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OPERATOR PSYCHOPHYSIOLOGY IN MAN-MACHINE SYSTEMS

By

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OPERATOR PSYCHOPHYSIOLOGY IN MAN-MACHINE SYSTEMS

Kiev PSIKHOFIZIOLOGIYA OPERATORA V SISTEMAKH CHELOVEK-MASHINA in Russian 1980 (signed to press 23 Nov 79) pp 2-342

[Book "Operator Psychophysiology in Man-Machine Systems" by Kirill Aleksandrovich Ivanov-Muromskiy, Oksana Nikolayevna Luk'yanova, Valentin Aleksandrovich Chernomorets, Konstantin Vladimirovich Lyudvichek, Vladimir Yevgen'yevich Alekseyev, and Dmitriy Ivanovich Chus', Ukrainian SSR Academy of Sciences and Order of Lenin Institute of Cybernetics, Izdatel'stvo "Naukova Dumka", 2,350 copies, 344 pages]

CONTENTS

[Text] Annotation

Research in recent years has graphically demonstrated the need to give special attention to the problem of raising the reliability of the "human factor" in control systems of varying complexity and purpose. Man-machine systems are much less efficient if the operators do not perform the duties assigned to them. This monograph presents results from monitoring the condition of the operator under experimental conditions, modified physical experiments, and in the human work situation in production. These findings were obtained through the combined efforts of physiologists, engineers, and mathemeticians.

The book is intended for specialists working in the fields of ergonomics, human factors engineering, and differential psychophysiology.

The book has 81 illustrations, 10 tables, and a bibliography that runs from page 314 to 343.

Foreword

Research in the field of neurobionics has become one of the most timely challenges of contemporary science and technology as the result of numerous factors: the accelerating pace of scientific-technical progress, the extensive development and introduction of general and enterprise automated control systems and the resulting need to improve the reliability of the man-machine system by insuring the reliability of the "human factor," the fight against nerve and psychological illnesses caused by the steadily increasing stresses on the human nervous system, and the search for possibilities of using the "concealed reserves" of the human brain.

The achievements of scientific-technical progress contrast starkly with the capability of human beings to control the functions of the human brain, in particular such complex functions as emotions, memory, and thinking. The reason for this is that we have insufficient information on the mechanisms of brain activity and do not have effective and adequate techniques for exercising a controlled influence on the nervous system as a whole and on the brain in particular.

Study of the role of the "human factor" in man-machine systems has become particularly important in recent years. This is related both to the fundamental aspect of the problem and to purely applied questions. With respect to the general approach to solving the problem, "the conception of full automation of information processing, which arose in the early days of the development of cybernetics and computer technology, has not withstood the test of time chiefly in connection with creative problems."[1] (This does not mean we agree that complete automation is impossible in general. But at the present time, the only way to set up qualitatively complex information processing systems is by devising man-machine systems.)

The problem of the artificial intellect occupies a significant place in pure research and development. Neurobionicists here are interested chiefly in the system and structural foundations of the organization of the activity of the natural intellect.

On the level of working out the biological foundations of the artificial intellect our collective has attempted to study and model human behavior in the process of decision-making and learn about human psychophysiology in conditions where the distinctive features of self-regulation of higher nervous activity resulting from genotypic and sociological factors are most vividly manifested, in particular under conditions of stress.

In working out the foundations of the artificial intellect it is important to insure optimal interaction of the human being and the machine so that, as V. M. Glushkov observed, "each side gets room to use its own best talents."

In the applied sense the "human factor," as a term that appeared in the very beginning of the development of ergonomics and human factors engineering, has recently been formulated as follows: "Human factors are integral characteristics of the link between the human being and the machine which manifest themselves in concrete conditions of interaction between them during the functioning of a man-machine system related to achievement of a concrete goal. But the characteristics and properties that are embraced by the concept of human

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[1] Glushkov, V. M. et al, "Chelovek i Vychislitel'naya Tekhnika" [The Human Being and the Computer], Kiev, "Naukova Dumka", 1971, 272 pages.

factors are not distinct, separate qualities of the components of the man-machine system, but rather its aggregate, system qualities."[2] "Human factors, understood as the key integral characteristics of the man-machine system, thus represent a certain superposition of the initial indicators, and correspondingly also represent fixed or dynamic functional links among components of the man-machine system."[3]

If the term "human factor" is translated into the language of objective statistics, we obtain some very impressive figures. Thus, only 8-16 percent of the persons employed in the different sectors of production meet the occupational requirements with respect to psychophysiological characteristics. This factor is responsible for more than 40 percent of the highway accidents, 65 percent of the industrial injuries and accidents in deep underground coal mining, and 80-90 percent of the violations of operating conditions at thermal power plants.[4] An analysis of 545 aviation disasters in the United States (based on information in the foreign press) showed that 50 percent of these disasters occurred because the aircraft design did not correspond to the psychophysiological capabilities of human beings, the pilot had inadequate flying skill, the functional state of the organism was disturbed, or the level of psychological readiness for flying was low. According to information from the United Nations, 72-80 percent of highway accidents, which kill 250,000 persons a year and injure 7 million, occur through human fault. In 63.3 percent of the cases where ships collide and sink human error is also at fault.

It is for precisely this reason that we have concentrated our attention on the questions of human work in extreme conditions of the man-machine system, in biotechnical systems, on modeling the activity of the human operator, and on developing a system-structural approach to studying the reliability of human operators which envisions an evaluation of their actions from the sociological, psychological, and physiological standpoints. During this we consider predicting human actions based on evaluations of the individual's personality traits and current states. At the same time we attempted to automate the processing of data from psychophysiological and seminatural experiments and the results of study of human activity under work conditions.

All of these studies are the basis for the next stage of our development work: using neuroelectronic systems for learning and practical purposes.

The 1st International Conference "Bionics-75" recognized the creation of biotechnical systems, in particular neuroelectronic systems, as one of the principal areas of development of bionics. Research is being done in this area on

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2 Munipov, V. M., "The Current State and Developmental Trends of Ergonomics and Human Factors Engineering," VOPROSY PSIKHOLOGII 1978, p 60.

3 Ibid., p 61.

4 See, for example, V. A. Buzunov et al, "Physiological and Psychological Criteria for Occupational Selection in Occupations That Make Special Demands on the Organism," in "Tez. Dokl. 10-go S"yezda Ukr. Fiziol. O-va" [Abstracts of Reports at the 10th Congress of the Ukrainian Physiology Society], Kiev, 1977, pp 1-42.

different planes and the results deserve our attention.[5] The systems that envision active influence by physical and chemical factors directly on the substructures of the brain have even more interesting prospects.

Our studies fit into the area of such disciplines as human factors engineering and psychological bionics, about which V. V. Parin, F. P. Kosmolinskiy, and B. A. Dushkov have very accurately said: "One of the significant problems of human factors engineering is devising reliable systems of self-control and self-regulation for machines while the human operator continues to perform monitoring functions; this requires study and description of the mental processes in order to reproduce (model) them in technical devices and thereby transfer a number of functions to the machine."[6] These problems are matters for us to study later, although there is every reason to hope for significant results.

The present monograph is a summary of research done by physiologists, engineers, and mathematicians. The first two chapters and section one of chapter four were written by O. N. Luk'yanova and are devoted to labor, methods of identifying psychophysiological properties, the social orientation of the individual, and describing the state of operator activity in a stress situation. The third chapter, written by V. A. Chernomorets, describes the problem of increasing the efficiency of operator activity. The fourth chapter presents findings obtained from work under the direction of the author of these lines (K. A. Ivanov-Muromskiy) by the collective of the division of neurobionics of the Institute of Cybernetics of the Ukrainian SSR Academy of Sciences under both experimental and actual working conditions. The fifth chapter contains results from the work of K. V. Lyudvichek and V. Ye. Alekseyev on modeling operator activity. The model of group activity by operators is especially interesting in this part of the book.

Working in close contact with the bionics laboratory of KVVIAU [possibly Kiev Higher Military Aviation Engineering School], we considered it useful for the book to include findings obtained by D. I. Chus', a member of this collective (in chapter six).

The final chapter, written by K. A. Ivanov-Muromskiy with the help of Yu. V. Paramonov, is devoted to the future prospects of our activity, to the use of neuroelectronic systems whose principles our collective has been developing since 1967.

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5 See, for example, K. A. Ivanov-Muromskiy and Yu. V. Paramonov, "Ways to Realize Complex Biotechnical Systems," VISN. AN URSR, 1972, Vyp 11, pp 33-40; K. A. Ivanov-Muromskiy, "Elektromagnitnaya Biologiya" [Electromagnetic Biology], Kiev, "Naukova Dumka", 1977; N. V. Chernigovskaya, A. S. Putskerman, and S. Patolichchio, "Features of Directed Regulation of the Human Alpha Rhythm with the Use of Feedback," ZHURN. VYSSHEY NERVNOY DEYATEL'NOSTI 1978, No 3, pp 547-556.

6 "Kosmicheskaya Biologiya i Meditsina" [Space Biology and Medicine], Moscow, "Prosveshcheniye", 1970, p 143.

The authors express their gratitude to associates in the division of neurobionics at the Institute of Cybernetics of the Ukrainian SSR Academy of Sciences who took part in designing the data processing systems, discussing and planning the experiments, and mathematical processing of their results: E. T. Golovan', Yu. V. Paramonov, I. D. Ponomareva, T. A. Berezanets, T. M. Semik, L. I. Shumilina, M. D. Lobkova, T. M. Zyuganova, B. F. Sinel'nik, N. Ye. Afanasenko, and P. A. Petrenko, and also to A. N. Yanina for help in technical preparation of the manuscript.

Professor K. A. Ivanov-Muromskiy

Chapter 1. Labor and the Laboring Person

Labor and labor activities have been with humanity from the beginning. Labor is the great calling and means of self-expression of each individual person. People labor all their conscious lives in some field of social activity, attempting to reveal their talents as fully as possible. If a balance is found between individual capacities and the requirements of everyday activity, the person receives maximum satisfaction from the chosen form of labor. This is a rule for any person, for any occupation. It is in precisely this form of activity that a person can attain the heights of perfection.

Labor is always "functions of the human organism, and each such function, no matter what form and content it may have, is essentially an expenditure of the human brain, nerves, muscles, sense organs, and the like." [1]

Human beings carry on the process of labor using different technical devices which have ranged historically from the stone axe to the contemporary computer. Refinement of the forms of interaction between the human being and the technology has altered the requirements which the labor process makes of the human being. Whereas the initial labor process demanded that a person expend energy in the form of muscular force, at the present time people perform chiefly information functions, monitoring, programming, and controlling them. The refinement of the labor process has brought about a lowering of the physical requirements of the human organism and increased the importance of the psychophysiological traits of the individual. For this reason, studying the activity of the human operator is highly relevant today.

Considering the human being as a laboring individual K. K. Platonov [5] singles out four aspects: life experience, vocational training, forms of mental reflection, and biological and natural traits. We single out three aspects: the social (species and individual experience, training), the psychological (traits of reflection and thinking), and the biological (characteristics of the functional systems of the organism).

At the present time the problem of interaction between human beings and technical devices in the labor process is studied by various types of specialists, while the problem itself has become part of the subject matter of various scientific disciplines; psychology, labor physiology and hygiene, human factors engineering, vocational psychology, differential psychophysiology, and cybernetics.

Thus, we may draw the following conclusion: labor, which in K. Marx's expression [1, p 181] is a form of regulating the exchange of matter between human beings and nature, is thus the natural function of the human being and defines a person's full human essence. In turn, the human essence is revealed during labor activity. The specific labor process makes specific demands of the social and psychophysiological characteristics of the individual; the individual, depending on his or her inherent traits, puts an individual imprint on the occupation and creates what is called an individual style. In other words, we have a closed system: laboring person $\rightleftarrows$ labor, in which we may identify hierarchical levels that differ in complexity.

The techniques of investigating human labor activities and human interaction with technical devices can be classified on the basis of various factors: what aspect of the individual they help to study — sociological, psychological, and physiological; how the technique is accomplished — subjective and objective; how the degree of approximation to a real situation is achieved — questioning, laboratory modeling, actual activities; how active a role the investigator takes — observation and experiment; and finally, the degree of complexity — study of documents, questioning, observation, the labor method, experimentation, and testing.

Research usually begins with a study of documents. In this case the investigator becomes familiar with the autobiographical data of the test subject and studies the technology of the labor process, description of the equipment, and official records of the course of the labor process, accidents, injuries, and the like.

The next form of familiarization with the labor process and the laboring person is asking questions. This can be done in various forms, for example talking with the employees or with his or her fellow workers, chief, or manager. The conversation follows a prearranged plan. Answers to questions that are of interest may also be obtained by having a specially developed questionnaire filled out. Questionnaires are usually used for large-scale surveys. Under the questioning technique we should also include the many standardized test-questionnaires that aim at identifying (by behavioral reactions) certain personality traits. The best known of them are the Minnesota Multiphasic and the Cattel and Taylor tests [6, 7, 8]. The shortcoming in the questioning techniques is the subjectiveness of the information that the investigator receives.

A deeper study of the labor process, the requirements it imposes on human psychophysiological traits, and the dynamics of the condition of the working person is achieved in the stage of observation. Observation results can be represented in the form of a stenographic or other reports, motion pictures and photographs, time-and-motion studies, and the like. It is particularly important during observation to record the physiological indicators of the state of the subject being studied. In order to obtain more complete information on the state of the operator an effort should be made to record indicators of the activity of the primary functional systems of the organism: cardiovascular system (electrocardiogram, measurements of arterial pressure and blood volume per minute), central nervous system (electroencephalogram, rheogram),

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the respiratory system (pneumogram), the muscular system (electromyogram), and the involuntary nervous system (skin galvanic reflex). Additional information can be obtained by the labor technique that was broadly propagated and employed by Soviet vocational psychologists of the 1920's [5, 9]. In this technique the researchers themselves master the occupations they are studying.

The next stage in the study of human labor activities is the experiment, which enables the investigator to test a hypothesis that is formulated on the basis of observation, identify the essential operator characteristics in situations of varying complexity, and so on. Two types of experiments are distinguished: laboratory and natural.

The laboratory experiment may involve simulating actual activity (the synthetic experiment using trainers) or a particular operation (the analytic experiment with psychophysiological modeling). A laboratory experiment may also be done by mathematical modeling techniques where the investigator expresses the activities of the operator by means of formulas, equations, and the like derived on the basis of the findings of specialized writings or preliminary experiments. By solving these formulas and equations the investigator is, so to speak, studying human activities under particular conditions. By comparing the results obtained with actual events the investigator can determine the extent to which the mathematical model corresponds to reality. The laboratory experiment also encompasses tests made to identify or determine the measure of a particular psychophysiological trait of the operator ("achievement tests"). Tests are "brief, standardized psychophysiological examinations to establish, for practical purposes, interpersonal differences in intellect and so-called special capa-l...ities ["sposobnosti"], expressed in comparable quantities" [37]. The test subject must perform the action with an assigned precision within a set time. The tests are given in open form (the "paper and pencil" test) and in the form of an assignment using specialized equipment [10]. The advantage of the laboratory experiment lies in the possibility of receiving more accurate measurements of the parameters that interest us; the weakness is that it is not conducted in a real situation.

The natural experiment presupposes studies made right at the work position, which makes this a full-fledged method [5, 11]. Two types of experiments are distinguished depending on the purpose of the investigation. The first type contemplates an investigation of the behavior of the test subject when the investigator (unnoticed by the worker) causes some deviation from the usual course of the industrial process, some unforeseen situation, and the like; this is called the verifying experiment. The second kind, the formation experiment, investigates the formation or transfer of skills when mastering an occupation or undergoing retraining in connection with the introduction of some refinement, change in purpose, and the like. The verifying experiment enables the investigator to evaluate the significance of a particular property for operator activity in different conditions; the formation experiment enables him to form judgements about the mechanism or formation of labor skills and the possibility of one personal trait compensating for another in the process of mastering an occupation.

The investigator most frequently uses the scheme of techniques shown in Figure 1 to study labor activity and operator characteristics.

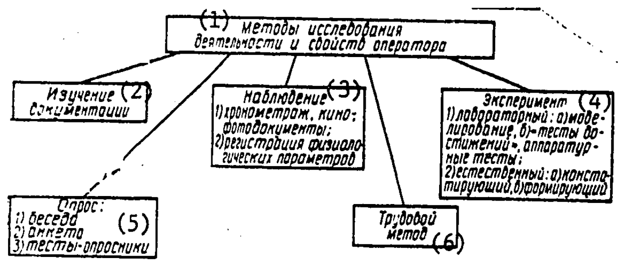

Figure 1. Methods of Studying Operator Activity and Characteristics

Key:
(1) Methods of Studying Operator Activity and Characteristics;
(2) Study of Documents;
(3) Observation — 1. Time-and-Motion Studies, Motion Pictures, and Photographs; 2. Recording Physiological Parameters;
(4) Experiment — 1. Laboratory Experiment: a. Modeling, b. Achievement Tests and Machine Tests; 2. Natural: a. Verifying, b. Formation;
(5) Questioning — 1. Conversation, 2. Questionnaire, 3. Survey Tests;
(6) Labor Technique.

All these techniques are used for the purpose of better adapting the labor process and implements of labor to human capacities and also to search for the optimal combination of personal characteristics to master an occupation and meet its requirements. Four problems are singled out depending on the aspect of study: (1) rational organization of the schedule of labor and rest; (2) vocational guidance and selection; (3) organization of training; (4) reconciling human capacities and machine requirements (human factors engineering). All of these questions are included in the problem of scientific organization of labor (SOL) in the broad sense (in the narrow sense SOL applies to rational organization of the schedule of labor and rest).

1. The Origin and Development of SOL [Scientific Organization of Labor]

The origins of scientific organization of labor go back to the period of the birth and development of the capitalist method of production, when the question of raising labor productivity became timely. It is customary to consider Frederick Winslow Taylor the founder of scientific organization of labor. In 1882 Taylor made studies of working motions [12, 13]. The purpose of his studies was to raise labor productivity. This was attempted by differential wages for workers and standardization and rationalization of particular labor operations. But Taylor and his followers ("Taylorism") did not take account of the individual qualities of the worker and did not strive for a scientifically substantiated organization of the schedule of labor and rest. In the pursuit of maximum profit the system which they proposed squeezed every bit of strength out of the worker.

V. I. Lenin, while calling for us to "borrow everything valuable" from this school, exposed the predatory essence of Taylorism and called it "subtle savagery" [3, 4].

Scientific organization of labor began to be employed much later in Russia, even though the foundations for its successful development had been laid in the late 19th century by the work of I. M. Sechenov [14, 15].

The issues of scientific organization of labor received further development in the works of the vocational psychologists (a term introduced by the German scientist Stern). Two periods must be distinguished in the development of vocational psychology. The first was the pre-personality period when the investigators working on the problems of scientific organization of labor did not take account of the individual characteristics of the subject, which made this development similar to Taylorism. The German vocational psychologist Muensterberg was the major representative of this period. The second period is represented by the works on whose basis scientific trends such as vocational typology and psychological classification of occupations began to develop. The most striking representative of the ideas of this period was O. Lipman [16]. In his work "On the Psychology of Occupations," he reviews the requirements which different occupations make of a person and the relationship between occupational style and the person's individual characteristics.

The school of Soviet vocational psychologists took shape in the 1920's and 1930's. Its founders were S. G. Gellershteyn, S. L. Rubinshteyn, and I. N. Shpil'reyn. Permanent psychological offices and laboratories were opened at many enterprises through the efforts of the vocational psychologists. The labor technique that has already been mentioned appeared during these years. An all-Union congress of vocational psychologists and the 12th International Conference of Vocational Psychologists were held in Moscow in 1931. In later years, however, work on vocational psychology was stopped in the USSR. There were two reasons for this: first, the USSR was experiencing an acute shortage of labor in connection with rapid development of its industrial potential (and for a time vocational selection was not a paramount task), and secondly, the fundamentals of vocational psychology diverged from the fundamentals of general psychology, which found expression in undesirable turns and scientifically unsound methodological approaches. Large-scale work on scientific organization of labor began again after the 1957 conference on questions of labor psychology, which censured the shortcomings of vocational psychology, and particularly after the 1967 all-Union conference on labor organization. At the latter meeting, in connection with the directives of the 23rd CPSU Congress, practical recommendations were developed to intensify scientific research on the physiology, psychology, and hygiene of labor. The 2nd All-Union Congress of the Society of Psychologists in 1963 already had a working section on human factors engineering, and at the 3rd All-Union Congress of Psychologists in 1968 there were sections on labor psychology and human factors engineering. Many fundamental works were published on reconciling the subjective and objective factors in production, a characteristic problem of human factors engineering [17-21]. During these years a number of major works on the physiological, psychophysiological, and psychological aspects of labor organization appeared [23, 28-32].

The first all-Union conference on "The Human Being and the Automaton" was held in 1963. It marked the beginning of a broad range of domestic works on the problem of the man-machine system (MMS). This line of study is characterized by development of the systems approach under the influence of cybernetics in considering the interaction of human beings and technical devices [22, 23-27].

A new stage in the development of SOL took shape abroad also [33].

All the areas of SOL are developing successfully today: vocational selection; vocational training; scientific organization of the schedule of labor and rest; and, human factors engineering.

2. Classifications of the Types of Human Labor Activity

The specific features of the tasks, methods, means, and measures of SOL depend on the type of labor activity for which it is being developed. We have already observed above that labor activities in their historical aspect have changed from labor processes that required physical characteristics of a person (strength, agility, and endurance) in the first stage to primarily operator types of labor today, a time of universal introduction of full mechanization and automation of production (tracking, monitoring, programming, and control). The human functions have also changed in this connection, from energy functions to information functions.

We still keep the division of labor into physical and mental labor today [34, 35], but fewer and fewer production processes require physical labor, and it is usually not in direct form. These two large classes of labor activity impose demands on different functional systems of the human being and are described depending on this as muscular and nervous activity or physical and mental labor (see Figure 2 below). The criteria of difficulty for the particular types of activity can be a physical measure of labor for the first class of labor operations and intensity for the second class [35]. The physical measures of labor are expressed in kilogram-meters of work done or in gigacalories of energy expended. For example, jobs that require more than 4.17 gigacalories per minute are put in the middle category of heavy physical work.

The intensity of labor is usually determined by the density of various types of information which the operator must receive during a working day. When evaluating intensity it is essential also to evaluate the rate and evenness with which information arrives, the ratio between primary and secondary information, and so on. The second class of human labor activity can be broken down into subclasses which have their own specific features. For example, in her work, V. P. Solov'yeva [36] studies the following subclasses: (1) mental labor without nervous-emotional stress (the labor of a proof reader); (2) labor with nervous tension but without mental stress (a subway engine driver); (3) mental

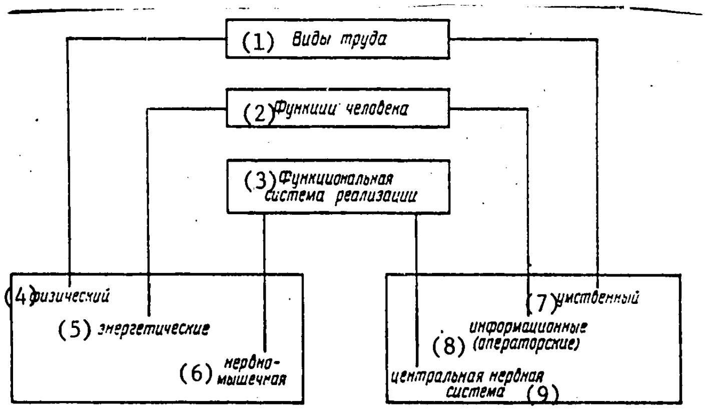

Figure. Types of Labor

Key: (1) Types of Labor;
(2) Human Functions;
(3) Functional Systems Used;
(4) Physical;
(5) Energy;
(6) Nerve-Muscular;
(7) Mental;
(8) Information (Operator);
(9) Central Nervous System.

labor with nervous-emotional stress (a dispatcher at the console); (4) creative mental labor with differing degrees of nervous-emotional stress (junior and senior scientific associates, graduate students).

K. M. Gurevich [37] classifies occupations by the intensity of labor (intense at all times, at certain times, and at indefinite times) and by the presence of strain on the emotions and the will.

All of these classifications are constructed depending on which sphere of activity and which human functional system receives the primary burden. In addition, attempts have been made to classify occupations according to the potential and characteristics which a working person must have to successfully perform the labor process. Thus, Lipman, who was one of the most prominent representatives of the personality stage of vocational psychology, had already divided all occupations into two categories [16]:

1. The higher or "intellectual" occupations, characterized by the lack of a standard style of performance. A person who has mastered a higher occupation shapes this occupation to some extent depending on his or her own individual characteristics. Examples are doctors, artists, and the like;

2. The lower occupations, which require elementary, standard qualities for their performance. Examples might be work on a conveyor line, sorting, and the like.

In addition to the psychological classification of occupations, Lipman also worked out an occupational typology. He asserted that the phlegmatic was more interested in learning, while the sanguine was more attracted to doing.

K. M. Gurevich [37] divides occupations into two types depending on the categories of requirements which the occupation makes of individual human characteristics: (1) occupations that absolutely require some anthropometric or psychophysiological characteristics (for example, reaction speed for a jet pilot, strength for handling a sledgehammer); (2) occupations that make compensible requirements for individual characteristics. For example, people who differ in the speed of their thinking processes can successfully master the same occupation. Some will handle the job quickly and easily because their thinking processes are very fast; others who spend more time on the thinking process also do the job well thanks to their diligent care.

3. Scientific Organization of the Schedule of Labor and Rest

When working out the foundations and concrete steps of the scientific organization of the schedule of labor and rest, the investigator identifies first those factors which directly or indirectly influence the production indicators of the worker and how he or she feels. There are some 2,000-3,000 such factors, but they can be classified by groups. A. I. Prokhorov [38], for example, identifies seven groups of factors: 1 — the type, character, and complexity of the task; 2 — the character and characteristics of the person; 3 — organization of the work position; 4 — organization of production activity; 5 — conditions of activity; 6 — motivation for activity; 7 — objective conditions of the setting of the activity. These are fairly broad groups and any factor can be reflected in them. Other investigators propose a division of influential factors that differs from this one by using narrower and more concrete groups. For example, A. I. Samoyolova [39] feels that SOL measures should be concentrated on the following factors: the pace and rhythm of the production process, the equipping of the work position and work posture, the schedule of labor and rest, the microclimate, the air environment and illumination of the work position, special work clothing and environmental esthetics, and organization of a rational diet.

In the work of A. A. Adamovich-Gerasimov and others [40], the factors which must be taken into account in studies of SOL are broken down into physiological, psychological, sanitary-hygienic, sociological, and technical-economic.

N. D. Levitov [41] identified three groups of factors on which success in mastering an occupation and attaining high production indicators depends: motivational components (the status of the occupation in society, wages and working conditions); qualifications components (the level of training and natural capacities), and the individual psychophysiological characteristics.

K. K. Platonov [5] believes that scientific organization of labor should look first at the impact of the environment, in particular the working collective, as well as the presence of factors that have a negative impact on the worker's health, the development of occupational fatigue, and characteristics of the mental processes and emotional sphere of the worker. The work of V. G. Zhukov and R. I. Ignat'yev [35] assigns the primary role to the sanitary-hygienic conditions of labor (condition of the work position), the schedule of labor and rest, the equipping and mechanization of jobs, and taking account of changes in work capability during the day and the week.

It seems to us that the factors which are reflected in the labor productivity, work capability, and physical and mental feelings of the worker can be classified in four groups.

1. The specific characteristics of the assignment: requirements of the occupation; complexity, type, and character of the task; degree of responsibility.

2. The potential of the person performing the assignment: experience of life, motivation, and interest; psychophysiological characteristics, sex, age, physical measurements, state of health, and behavior in ordinary and emergency situations; vocational training and qualifications.

3. Organization of the labor process: scientific-technical advances in the particular sector of labor, furnishings and technical equipment of the particular production area, organization of the work position; pace, rhythm, and sequence of operations, rest periods, and industrial calisthenics; relations within the collective, the necessity of interaction with other members of the collective in the production process; meeting sanitary-hygienic and physiological requirements, the presence of harmful factors; esthetics, special work clothing, organization of the diet, and availability of rest areas.

4. Changes in functional state and work capability: during the working day; during the work week; related to the person's biorhythms.

After selecting a particular production area or type of activity for study, the first thing the investigator must do is write up a so-called "professiogramma," which contains a description of the occupation, the place of the occupation in the technological sequence, the principal working operations, the work position and sanitary-hygienic conditions, the required level of education, and the psychophysiological requirements imposed on the worker [42]. Then the list of indicators of activity is compiled [43]. Thus, the work of an operator in charge of several weaving machines consists of orientation (surveillance of the machines) and actuating activity; the latter is divided, in turn into preventive and urgent (special) operations. The list of indicators of activity also includes the walking movements of the weaving machine operator to inspect the machines, do preventive work, and perform special operations.

The time of the labor process is divided, in conformity with the purpose of the work being done, into primary time (used for special jobs) and auxiliary time (preventive work and inspection); taken together they determine the operational time of the working day. The working day of work time consists of operational time (primary and auxiliary) and breaks for rest, meals, industrial calesthenics, natural needs, and enforced idleness related to incorrect labor organization.

The list of occupational requirements with respect to the characteristics and qualities of the worker is a mandatory element in the description of the particular type of labor activity. This list is compiled on the basis of the findings of the specialized literature, personal acquaintance with the production area, and consulting with experts. By evaluating each requirement in connection with its significance for successful performance of the assignment the investigator receives a table, graph, or diagram of the distribution of the significance of the occupational requirements [5, 44]. Then the investigator determines the workload which the worker experiences during the working day. It is measured, as already mentioned above, in physical terms for physical labor and by intensity for mental labor. But the workload of different types of jobs cannot always be defined unambiguously by one of these criteria.

The workload is usually a multidimensional indicator. It depends above all on the pace of performance of the work or receipt of information, on the evenness of distribution of the workload, the required precision in performance of the assignment, the seriousness of consequences in case the worker makes mistakes, the degree of responsibility, the complexity of the algorithm of activity, and so on.

The next indicator of the person's activity, the productivity or efficiency of labor, is also multidimensional. Each form of labor activity has its own specific components. Thus, the efficiency of labor of a locomotive engineer [44] may be evaluated by three criteria: (1) reliability (accident-free work throughout the entire career; (2) skill rating; (3) conservation of electricity.

Techniques of recording the activity of different systems of the organism and functional tests are used to study change in the functional state of the worker, to determine indicators of functional state that correlate with changes in work capability, and to identify the moment of onset of worker fatigue. For example, the state of the central nervous system is determined by recording the biopotentials of the brain (electroencephalogram). An enormous amount of experimental material has now been accumulated on correlating changes in the electroencephalogram and the level of alertness, attention, emotional and operational strain, fatigue, and the like. Therefore, the electroencephalogram is a valuable diagnostic technique. The investigator may receive additional information about the state of the central nervous system by using various functional tests, in particular analyzing sensory-motor reaction time, recording the critical frequency at which flashes of light or discrete sounds merge, reacting to a moving object, picking up the rhythm of flashes of light or discrete sounds, tracking reactions, and other such tests.

The state of the involuntary nervous system (which often plays the main part in a change in functional state or increase in the workload on the worker) is studied by recording the frequency of the heart beat, arterial pressure, blood volume per minute, frequency of breathing, the ratio of inhaling to exhaling, the electrical resistance of potential of the skin (skin-galvanic reflex), body temperature and other such quantities.

Indicators of the activity of the muscular system depend on the functional state and the state of work capability. Therefore the electromyogram is studied and dynamic measurements are performed.

It is natural that the state of emotional and operational strain and fatigue are also reflected in higher mental functions. From this standpoint the indicators of the proof reading test have diagnostic value , as do other techniques: intertwined lines; the Schulte technique; adding numbers with carrying; and, reproduction of an image seen on a screen (shown for a minimum exposure of 0.05-0.15 seconds). These techniques can be used to form judgements on intensity, switching, attention span, and operational memory.

The spectral composition of operator speech "reacts" very subtly to changes in psychophysiological state. This enables the investigator to use the spoken answer as an additional indicator. Biochemical tests (change of sodium content in the saliva, sugar in the blood, urine composition, and the like) can also provide valuable information.

Recording indicators of the activity of different systems of the organism and establishing the labor productivity and work capability of the obligator enables the investigator to follow changes in these quantities during the working day, work week, and work year.

Early in the 20th Century E. Krepelin described the classic work curve. Ye. A. Derevyanko modernized this curve (see Figure 3 below). He showed how maximum capacities, the productivity of activity, emotional tension, and the state of fatigue change at different points in the working day. The periods of labor activity in the course of the day differ by time boundaries and quantitative expressions depending on the type of labor activity, years of experience, age, sex, and characteristics of the operator, but they are governed by the pattern described.

For practical purposes a less refined division of working time into three periods is usually used: 1 — period of beginning work and moving into a work rhythm, characterized by a gradual increase in work capability; 2 — period of stable maintenance of the level of work capability attained; 3 — period of decline in work capability, fatigue. This sequence of periods during work time is repeated twice, at the start of the working day and after the mealtime break [35]. Investigators note a similar progression in the work week [40]. And investigators studying change in the operator's work capability must consider not only the pattern described above, but also the influence of various factors (years of experience, age, sex, and personal traits) on it. In addition, the changes in work capability depend on biorhythms, in particular the 24-hour (daily) rhythm. It has been established [42] that changes in work capability and functional states are greater and the time required to get into a work

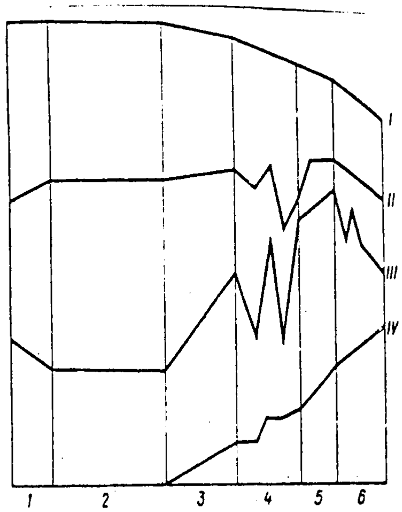

Figure 3. Work Curve (by Ye. A. Derevyanko, 1959):

Key: (I) Level of Maximum Capacities;
(II) Level of Productivity of Activity;
(III) Level of Emotional Tension;
(IV) Level of Fatigue;
(1) Period of Settling Into Work;
(2) Period of Optimal Work Capability;
(3) Period of Full Compensation;
(4) Period of Unstable Compensation;
(5) Final Spurt;
(6) Progressive Decrease in Productivity.

rhythm is longer for the second shift, while changes in biorhythms at the end of the shift are greater in amplitude.

Researchers have given special attention to studying the process of fatigue, which develops as the result of intense or prolonged work. Developing fatigue can be compensated for to some degree by motivational factors, efforts of will, and emotional factors. The following types of local fatigue are distinguished depending on the sphere of activity: physical, mental, and emotional. Fatigue may also be general in nature. The forms of manifestation of fatigue may vary depending on its type. Thus, V. P. Solov'yeva has demonstrated [36] that mental fatigue shows itself in the form of protective inhibition in the central nervous system (decline in the magnitude and speed of reflex reactions, reduction in the mobility of nerve processes, and increase in the inertia of the inhibitory process). Emotional fatigue is characterized chiefly by unfavorable changes in the cardiovascular system and biochemical reactions. Fatigue caused by mental activity with emotional stress shows itself in the form of changes in the central nervous system and the autonomous nervous system. Fatigue may be promoted by a diseased state, mental upset, and other indirect factors.

Prolonged fatigue that is not compensated for may lead to a transition from functional changes in the organism to organic ones. The nervous and cardiovascular systems suffer particularly in this case.

Measures for scientific organization of labor are worked out to preserve a high level of work capability and prevent fatigue in the worker. These measures, based on study of changes in the work capability and functional state of the worker in the course of the working day, aim at shortening and easing the period of getting into a work rhythm (initial exercises, removal of distracting factors, rhythmic music), prolonging the period of stable work capability (rational organization of the labor process and work position), and eliminating the first signs of fatigue (industrial calisthenics, instituting additional rest breaks, and consumption of vitamins).

Researchers have been particularly interested in the possibility of maintaining high work capability and a good general state by instituting short pauses, additional breaks of a few minutes (in addition to the basic mealtime break). It is most efficient to introduce 2-3 breaks of 5-10 minutes [35, 45]. In this period of time it is possible to restore functions without losing the work rhythm that has been achieved. The need for additional rest is determined by the magnitude of functional changes at a certain moment in time [35].

One of the ways to combat the development of fatigue is active rest, that is, industrial calisthenics or changing the work operations and emotional conditions. From the physiological standpoint these measures should lead to a change in the focus of stimulation in the brain. The new focus of stimulation restores the initial state that functioned earlier by inducing inhibition of neighboring zones [5, 30, 46].

Monotonous work makes special demands for SOL measures. By causing a decline in the level of alertness it may lead to accidents. This is especially dangerous in those cases where accidents may involve a danger to human life (for example, the engineer of a locomotive). The simplest steps to combat monotony are introducing outside stimulants, periodically changing rhythm and operations, and consolidating routine, monotonous simple operations into more complex and diverse ones [28].

The following factors may serve as indicators of a correctly organized schedule of labor and rest, that is, indicators of the effectiveness of SOL measures:

1. Productivity and economic efficiency of labor;

2. Satisfaction with work, mobility of personnel;

3. Level of work capability and general state during the working day, restoration of a normal state after work;

4. Number and duration of cases of temporary inability to work, injury, and chronic illness.

Thus, we can identify the following stages in the work of an investigator studying scientific organization of labor [139]:

1. Study of existing physiological-hygienic conditions of labor and organization of the labor process;

2. Characterization of work capability and the state of psychophysiological functions during work;

3. Analysis of the state of health (taking into account years of experience, age, sex, occupation, and social-domestic conditions);

4. Development of SOL measures;

5. Testing the effectiveness of SOL measures.

4. Vocational Guidance, Vocational Selection, and Vocational Suitability

An occupation (vocation) is a specific group of labor duties that has existed for a long time and took shape on the basis of division of labor. The specific group of labor duties requires that a person show qualities and characteristics that are specific to the particular occupation. Thus, K. Marx wrote long ago: "Different operations performed in turn by the producer of a good and merging into a single whole unit in the process of his labor make different demands of him. In one case he must develop greater strength, in another greater dexterity, in a third greater attentiveness, and so on" [2]. He continues, "But one and the same individual does not have all these qualities in equal measure " [2]. It follows from this that different people will perform the same work differently in qualitative and quantitative terms, using different amounts of strength and energy for this. The necessity of matching the capabilities (social, mental, and biological) of the working individual and the requirements of the occupation is the problem of vocational guidance and vocational selection.

The presence of the essential group of social and psychophysiological qualities and traits insures that the working individual will be successful in mastering the occupation, achieve highly productive labor, and be satisfied with the labor activity. These factors are the criteria for the occupational suitability of a working individual for a particular type of labor. But the tasks of vocational guidance and vocational selection are not limited to questions of occupational suitability. This is just one aspect of the matter, the humanistic side. Vocational guidance also considers the economic and social aspects of the question: the market for possible application of the labor and the social weight of the occupation in the given society. Figure 4 below shows the "vocational guidance triangle" and its forms [5]. Conflicts often arise between the humanistic and economic aspects. For example, in the first years of industrialization of our country when an enormous influx of labor was required for industry, work on the study of labor psychology, which had been conducted successfully by the vocational psychologists of the 1920's and 1930's was stopped.

Therefore, a researcher beginning work on the problems of vocational guidance, selection, and suitability with application to a certain sphere of labor activity must first of all study the following questions:

1. The economic or social need for the particular occupation;

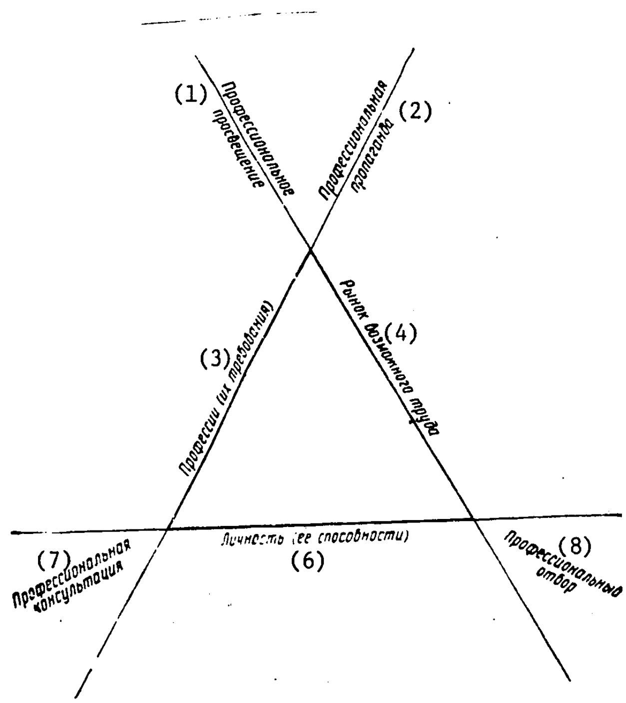

Figure 4. The "Vocational Guidance Triangle" and Its Forms (according to K. K. Platonov, 1970)

Key:
- (1) Vocational Education;
- (2) Vocational Propaganda;
- (3) Vocations (Their Requirements);
- (4) Market for Potential Labor;
- (6) The Individual (His or Her Capabilities);
- (7) Vocational Consultation;
- (8) Vocational Selection.

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2. The class of occupations involving the particular type of activity;

3. The social and psychophysiological demands of the occupation on the working individual;

4. The characteristics which a person must have to successfully master the occupation, achieve high work indicators, and receive moral satisfaction from the chosen type of activity.

Approaches to and views of the problem of the potential and capabilities of the working individual are not uniform. Thus, there have been different estimations of the importance of natural and acquired characteristics and of the manifestation of capabilities in different spheres of social activity. Some students of the question believe that a person is born with certain already established capabilities and that no education and training can replace them if they are absent. Others feel that a person is born with equal inclinations for all capabilities and that any capability can be perfected by education. In their works F. R. Dunayevskiy, A. K. Gastev, and others deny that there are persistent natural differences [48, 49]. They believe that a person can develop any quality through long, hard work.

It is apparent that an orthodox defense of either the first or second point of view leads to incorrect conclusions. A third point of view on the development of capabilities is given in the works of I. P. Pavlov and was formulated well by K. K. Platonov [5]: "Capabilities are a fairly stable structure, but of course they also change under the influence of education and the individual psychological characteristics of the personality." This point of view takes account of the importance of both the inborn biological principle and the acquired, social principle.

We have considered views concerning human capabilities with respect to mastering a particular sphere of activity. Views also differ as to the categorical nature of the requirements which an occupation imposes on a person. Thus, some researchers feel that in principle any person can master any occupation, although the person may not always have all the characteristics needed for the particular occupation in the necessary degree [43, 50]. This occurs through compensation for some characteristics by other characteristics. Thus, high indicators in any type of activity can be achieved by workers with the most diverse psychophysiological structure, by means of different personality traits that are reflected in the individual style of work. Therefore, occupational selection is not decisive. Primary attention should be focused on constructing adequate training programs that can develop the essential characteristic or a compensating one in order to meet the occupational requirements.

K. M. Gurevich elaborates a different point of view [37]. He believed that there are two types of occupations. The first type makes demands on the individual for which no compensation is possible. In this case there must be absolute vocational suitability, which requires careful vocational selection. The second type of occupation makes demands on the working individual which can be compensated for by different characteristics. The common occupations belong to this type. For them vocational selection is not so important and primary attention is given to correctly organizing training programs and methods. But even for the second type of occupations, despite the possibility of compensating for lack of some characteristics with others, not all persons who have mastered the occupation can attain the highest levels of skill. In this case, therefore, the compensatory potential is limited and vocational selection is desirable [51]. This conclusion is confirmed by the fact that a high percentage (up to 25 percent) of healthy people cannot master various occupations that differ by complexity because their nervous and cardiovascular systems become overloaded [52]. Thus, in vocational selection it is necessary to consider not only the existence of characteristics that insure vocational skill and the possibility of compensation for them, when lacking, but also the load on the organism in mastering the occupation and carrying on daily activity in the chosen sphere of labor.

The partial or complete unsuitability of a working individual for a particular type of activity may show up in different stages of acquiring vocational skills and in different situations when performing occupational duties. Thus, in the training process people whose characteristics are most in accord with the requirements of the future occupation master the vocational skills faster and more easily than people who do not have the optimal set of characteristics for the particular occupation. The latter may also master the occupational skills (compensation by other characteristics if it is possible, or persistent, correctly organized training of the essential characteristics), but they spend much more effort and time doing so.

Thus, a significant spread is observed between the first and second groups in the beginning, followed by a convergence of individual indicators of activity because the second group is raised to the standards of the occupation by compensatory individual characteristics [51]. Under ordinary working conditions in the second type of occupations (according to K. M. Gurevich), the difference in characteristics will not lead to a sharp divergence in indicators of labor activity. But the difference in psychophysiological characteristics shows clearly in unusual, stress situations. The stress may be the result [53] of the difficulty of the assignment (high requirements for precision and speed of performance, work when time is short, work under conditions of information overloads, and complexity of the assignments), when an emergency is highly likely or existing, when there are distracting factors, when an unforeseen change occurs in the ordinary course of the labor process, and so on. Failure to match the optimal set of characteristics also fosters excessive nervous tension in the worker; which may result in serious chronic illness.

These factors (taking economic and social need into account, of course) demonstrate the necessity and usefulness of vocational guidance and vocational selection.

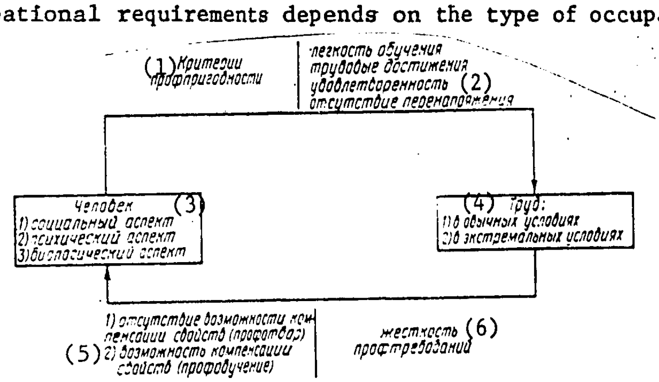
Vocational selection is done as follows. First the researcher becomes familiar with the occupation and establishes its classification, place in the economy, distribution, and future prospects. The "polytechnic" quality of an occupation is important to study, because this makes it possible in part to apply the results obtained to other areas of activity. Next a list is made of the operations that make up the occupational activity. The operations must be broken down into basic (ones on which performance of the assignment as a whole directly depends) and subsidiary (preparatory and prophylactic) operations. It is desirable to rank the operations by time spent and difficulty of performance. The investigator can use any of the methods described above for this purpose.

In conformity with the occupational description obtained in this manner, the researcher should make a list of the requirements that the occupation imposes on the working individual. For example, the following list of requirements is used for vocational selection of locomotive engineers [44]: perception, attention, memory, ability to make decisions under time pressure, and emotional stability. The questionnaire composed by Lipman is usually used to identify psychophysiological requirements; ordinarily it is adapted in advance to the occupation under study [5]. Then the investigator, beginning with knowledge that has been accumulated in the special literature, personal experience, and the findings of preliminary experiments, determines the characteristics which a person must have to master the occupation and perform its operations. After this vocational selection proper is done. This usually begins with a medical examination and ends with identification of the social orientation and determination of the psychophysiological characteristics of the individual, his or her compensatory potential, and the need to develop and drill vocational capabilities.

Training is a key element in the preparation of workers for occupations. The training program must take into account compensatory potential and the need to develop and train occupational capabilities.

The specific features and significance of the occupation determine the degree of strictness in vocational selection, whether it is done according to the upper or lower boundary of the criteria used.

Thus, vocational guidance and selection should include three basic stages: compiling an occupational description and list of psychophysiological requirements of the occupation, identification of the essential capabilities, and working out ways to develop these capabilities. Figure 5 below diagrams how the criteria of mastering an occupation depend on the potential of the person and how the strictness of the occupational requirements depends on the type of occupations.



Chapter 5. Criterion of Vocational Suitability

Key:
(1) Criteria of Vocational Suitability;
(2) Ease of Training, Labor Achievements —, Satisfaction, Lack of Excessive Stress;
(3) The Person — 1. Social Aspects, 2. Mental Aspects, 3. Biological Aspects;
(4) Labor — 1. In Ordinary Conditions, 2. In Extreme Conditions;
(5) 1. Lack of Possibility of Compensating for Characteristics (Vocational Selection), 2. Possibility of Compensating for Characteristics (Vocational Training);
(6) Strictness of Vocational Requirements.

Chapter 2. Investigating the Psychophysiological Characteristics and Social Orientation of the Individual

The methods used by the investigator in vocational selection must be (as in any investigation) adequate and informative, that is, they must directly identify the characteristic under study and describe it as fully as possible. Various methodological procedures can be used to study the individual person: interrogation, observation of behavior (in ordinary life, on the job, and in the training process), and tests (paper and equipment tests).

It is customary to consider Taylor, who in the 1880's used testing as a technique for vocational selection in order to raise labor productivity, the founder of testology. Later testing was used as a method for determining the mental capabilities of school children [54], and during World War I as a method for assigning soldiers to particular branches of the military. Tests administered using fill-in blank forms are a fast technique of investigation suitable for large numbers, but for the most part they do not identify inborn characteristics (individual inclinations), but rather acquired knowledge and experience. This is especially typical of verbal tests which immediately assign a semiliterate person to the lowest level of the evaluation scale, even when the person may possibly have good natural gifts. Therefore, in the hands of racists and advocates of class differences verbal tests became a discriminatory weapon and in this way discredited the idea of testology. Tests which use pictures are to some degree without this shortcoming.

Therefore, tests can be used primarily to determine the level of general human and vocational sophistication acquired at a given moment in time and are much less useful to identify inborn capabilities, intellect, and distinctive features of a person's thinking.

Equipment tests involve technical devices which chiefly investigate the characteristics of the central nervous system, higher nervous activity, the autonomous nervous system, and other functional systems of the organism.

Now let us consider the most widely used specific techniques of studying the individual personality for the purpose of identifying its individual traits and the characteristics of its organization.

The social aspect of the individual personality includes character traits (adherence to principle, honesty, initiative, activism, organization, optimism, pliancy), social consciousness (patriotism, progressivism, moral makeup, collectivism, atheism, and attitude toward oneself, other people, and labor), capabilities (psychomotor, artistic, technical, mathematical, musical, literary, scientific, organizational, and so on), experience of life, general level of sophistication, upbringing, and vocational training (qualifications, time of service). The motives that inspire activity by the working individual and the person's interests occupy a special place in the social aspect.

The investigator obtains information on these matters by studying references, autobiographies, personal records and other documents, applications, and questionnaires filled out both by the subjects themselves and by persons around them. The investigator also learns about the person in the process of personal interviews and interrogation.

Each sociological investigation is a new creative process, and its success depends on the inventiveness, knowledge, and practical skills of the investigator. Therefore, the experimental method [55, 56] is the principal method in sociological research.

The psychological aspect of the personality is described in terms of the characteristics of mental forms of perceiving and reflecting the world: attention, emotions and feelings, memory, and thinking. When considering the emotional sphere of a person and describing it, it is also essential to investigate the person's volitional (will) capacities because the behavior of a person in emotive situations depends on the characteristics of this purely human quality (degree of fearlessness, decisiveness, persistence, self-control, purposefulness, and discipline).

The correction test method is used to determine the stability, distribution, and concentration of attention [5, 57, 58, 59]. The test subject is given a blank with a series of letters on it and told to cross out a certain letter. In a second variation the subject is told to cross out one letter and underline another letter. The test lasts a few minutes (usually up to five minutes), and on a signal from the experimentor the test subject marks the form after definite time intervals (30 seconds). A table with Landolt rings can be used instead of a form with letters [60, 61]. The degree of stability of concentrated attention can be established by the intertwined lines technique. Several lines (10-25) are intersected a number of times on the blank. They all start and end in boxes on the right and left sides of the paper. Their ordinal numbers are placed on one side of the sheet. The subject must visually trace the line along its entire length and put its number in the appropriate box on the opposite side of the sheet [5, 62].

Switching attention can be analyzed by the method of adding numbers with switching [5]. The test is done in two ways. The first way is as follows: two one-digit numbers are given in fraction form; they must be added and the total entered in the numerator in the second row on the right, while the numerator of the first proposed row is put in the denominator of the second row, and so on. In this case, if the total is more than 10 only the the one's digit is written.

$$\frac{4}{2},\ \frac{6}{4},\ \frac{0}{6},\ \frac{6}{0},\ \frac{6}{6},\ \frac{2}{6},\ \frac{8}{2},\ \text{and so on.}$$

When the second method is used, the total of the numerator and denominator of the first row is put in the denominator of the second row while the numerator of the second row becomes the denominator of the first row. The methods are alternated by instructions every 30-60 seconds. Switching of attention (which evidently is accomplished chiefly by the speed of mental processes and the ease of formation and modification of the mental habit) can be considered easy if a subject is able to perform 20 or more additions in a minute. Switching is difficult if the subject performed 10 or fewer additions.

The volume and distribution of attention can be investigated by the Schulte method. It goes as follows. The subject must quickly find and point out a natural series of numbers of a given length in a table consisting of an appropriate number of boxes in which numbers are written without order. The test can be made more difficult by introducing different number types and sizes in addition to the random arrangement of numbers [62].

K. K. Plantonov [5] proposed a modification of this technique (called the Schulte-Platonov method) which makes it possible to test the volume, distribution, and switching of attention. Numbers from 1 to 25 are written without any order in two colors in a table. The test subject must quickly name and point out the numbers in order, beginning one colored series from the largest (in descending order), and the other from the smallest (in ascending order). The different colored numbers are found in alternation (for example, red 25, blue 1, red 24, blue 2, and so on). Attention volume can also be studied by the method which K. K. Platonov [5] described as controlled display of a card with 16 boxes on a tachistoscope (exposure time varies from 0.05 to 0.15 seconds). Some (2-8) of the boxes contain dots. The subject must be able to remember them and write them in on a blank form. Memory volume is determined by the number of dots accurately reproduced on several cards. The accuracy of perception is the average percentage of correctly reproduced dots on all the cards, and depends on the time of exposure, the complexity of the cards, and of course, on the characteristics of the test subject.

Operational (short-term) memory is an important quality for the operator in many production processes.

At the Institute of Hygiene and Occupational Illness (Ukrainian SSR) this kind of memory is investigated by a technique which involves direct memorization of geometric shapes and subsequently recognizing and selecting them. The test subject is given an assignment card to memorize. It represents six equivalent triangular shapes with different internal hatchures. In addition to the assignment cards, a file case containing 24 figures, including the ones represented on the assignment cards, is also used. The time allowed to memorize one card is 10 seconds. Then, in the file case, the subject must find the figures that were displayed. One minute is allotted for recognition and selection. The number of figures correctly recognized and selected is the indicator of short-term memory.

Many types of activity make special requirements on characteristics of a person's thinking. Thought is that mental activity (at the level of the secondary signal system) which aims at knowledge of objective reality by identifying linkages and relationships between the objects and phenomena under consideration. Characteristics of thinking include the capacity of the working individual to make optimal decisions in time, to diagnose the state of the entire labor process by particular manifestations, and to monitor correct performance of particular operations. The characteristics of a person's thinking determine the ability to plan strategy and tactics, the creative approach, and inventiveness.

The speed of thinking processes is especially important. It can be measured, for example, with the set of tests proposed by the English psychologist Eysenck [63]. In the author's opinion, these tests measure a coefficient of intellect [Russian abbreviation "KI," possibly English "IQ"], which correlates significantly (but not exhaustively) with speed of thinking operations. Thirty minutes are given to perform each test. The number of problems correctly solved in this time is the index of the coefficient of intellect. Eysenck believes that the coefficient of intellect reflects two aspects of intellectual development: the genetic, inborn foundation — the speed of thinking processes, and the social-psychological experience of the particular social group. The tests which he proposes have the same shortcomings as other fill-in blank tests. When evaluating this method it is essential to consider that these tests reflect socioeconomic status more than the inborn foundation of intellectual development [64].

To reduce the contribution of the social factors to the evaluation of capabilities some psychologists propose that the index of intellectual capabilities be considered not the absolute number of problems solved by the subject, but rather the rate of increase in this number when three or four successive tests are given. There are also several other methods of testing intellect [6].

The emotions and feelings of a person are one more form of mental processes which make an imprint on the person's behavior and labor activity [65]. Emotions are the simplest form of reflection (at the level of the primary signal system) and reveal relationships between environmental influences and the biological needs of the organism. The limbic system is the morphological substrate of the emotional processes.

The feelings are the most complex form of reflection, characteristic only of human beings. They occur following the pattern of the conditioned reflex and must involve participation of the cerebral cortex. The feelings reflect relations between the external world and a person's social needs.

The emotions are generated directly by the perception process, whereas feelings arise indirectly through comprehension of what has been perceived. The difference in the morphofunctional substrate of these two forms of reflection also gives rise to different possibilities of shaping and controlling these processes. Thus, feelings can be effectively influenced by word stimulants, while a particular emotion can most easily be supplanted by a stronger emotion.

Each person has his or her own quality and intensity of emotional manifestations. Depending on the nature of their emotional spheres, different people behave differently in the very same dangerous situation [5]. A distinction is made among the asthenic reaction or the passively defensive reaction (becoming numb, purposelessness of actions, and immobilization), the sthenic reaction which follows the type of the actively defensive reflex (panicky behavior), and the sthenic reaction that expresses itself in militant excitation. The first two types of reaction are unconditioned reflexes, occur with participation of the primary signal system, and are classified with the negative emotional manifestation. The third type is one of the conditioned reflexes and results from the operation of the secondary signal system. At the present time there are virtually no methods that allow an objective evaluation of the quality and intensity of a peson's emotional makeup. But work in this direction is underway, in particular at the Institute of General and Pedagogical Psychology (Moscow) under the direction of A. Ye. Ol'shannikova [66]. A number of techniques have been developed which use interrogation to establish the sign and modality of the emotions typical of an individual in different life situations and to analyze their dynamic parameters (intensity, duration, and lability).

A. Ye. Ol'shannikova also attempted to establish a relationship between the sign of the dominant emotions and the background EEG [67]. She showed that test subjects in whom the positive emotions typically predominate have lower values for the energy indexes of the Delta, Theta, and Beta rhythms.

The volitional (will) qualities of the individual are very important for emotional-type reactions. They can suppress fear of real, existing danger and even evoke positive emotions.

Attempts have now been made to evaluate volitional qualities characteristic of a particular individual in quantitative terms. The Institute of Psychology in Kiev [9], for example, has developed a special instrument called a voluntograph. The device consists of two dynamometers which the test subject must squeeze with the right and left hands. The subject's volitional effort is measured by the number of correctly performed assignment cycles or the amount of work which the subject does on the condition of maintaining an assigned level of effort for the maximum possible time. S. V. Korzh [68] proposes measuring volitional efforts by the maximum time subjects can deliberately hold their breath.

In these cases the volitional effort will, of course, be closely related to the individual's specific physical development. But according to experimental studies this does not always correlate with intellectual volitional effort [69]. The latter is better studied, for example, by the Thornton test. The essential feature of this test is that the subject must "restore" a specially garbled text. Koos cube problems are suitable for this purpose. The subject is told to compose several figures from cube pieces, and the last assignment is insoluble. In this case the volitional efforts are determined by the time the subject spends trying to compose the required figure.

The inborn characteristics of the nervous system are the third aspect of the personality and constitute the object of study for a large branch of physiology, differential psychophysiology.

The foundational development of the problem of individual differences in the nervous system came in the work of I. P. Pavlov and his school. I. P. Pavolv formulated the principle of the fundamental characteristics of the nervous system (strength, equilibrium, and mobility of nerve processes), which is the cornerstone of the hypothesis of four types of higher nervous activity [70].

Further studies done in the laboratories of B. M. Teplov, B. G. Anan'yev, V. S. Merlin, and V. D. Nebylitsyn led to elaboration of the ideas developed by I. P. Pavlov and raising them to a qualitatively new level. They showed that the entire diversity of psychophysiological human types cannot be reduced to four variations. They formulated the conception of basic characteristics of the nervous system, "which assumes as its leading premise the proposition that a highly organized nervous system has a number of characteristics that describe the course of nerve processes of stimulation and inhibition in it and, in their combinations, make up the neurophysiological foundation of the varied psychological manifestations with their individual variations." [71, 72].

The following scheme of nervous system characteristics was compiled by B. M. Teplov and his students, and with particular clarity by V. D. Nebylitsyn [73].

I. Particular characteristics of the nerve processes of stimulation and inhibition of the nerve substrate which receives primary sensory information (that is, the analyzer):

a. primary particular characteristics: strength — the ability of nerve cells to endure prolonged, concentrated stimulation without switching to a state of beyond-the-limit inhibition ; mobility — speed of alternation of stimulation and inhibition and vice versa; dynamism — ease with which the nervous system generates the processes of stimulation and inhibition, in particular during the formation of temporary linkages; lability — speed of the activity of the nervous system, which is determined chiefly by the speed of extinguishing the aftereffects from a stimulation pulse, that is, speed of replacement of one cycle of stimulation by another when stimuli are fed in series. The primary characteristics describe changes in the fundamental nerve processes, stimulation and inhibition , respectively;

b. secondary particular characteristics: balance or equilibrium of nerve processes — stimulation and inhibition — for each of the primary characteristics (strength, mobility, dynamism, and lability).

It should be observed that sharply expressed differences among analyzers of primary and secondary characteristics are seen in 20-25 percent of the people (therefore, the particular analyzer for which the characteristic was determined should always be pointed out). The particular characteristics give partial information on the role of neurophysiological parameters in the dynamics of mental function, so consideration of the particular characteristics alone results in an incomplete picture of the neurophysiological foundations of individual differences.

It is necessary to study the general characteristics of the nervous system, the determinants of individual features of behavior and its most general manifestations, to explain individual differences not only in those domains of the psyche directly related to the function of the sense organs, but also those domains which relate to the personality generally.

II. The general characteristics are reflected in the physiological parameters of the processes of stimulation and inhibition of complexes of brain structures not directly related to receiving primary sensory information. These include the parameters of the nerve organization of brain regulatory formations. V. D. Nebylitsyn [73] considered two general characteristics: general activity and emotionality. These characteristics may be similar to extrovertism/introvertism and neuroticism in Eysenck's typological scheme [74]:

a. general activism according to Nebylitsyn — this refers to the personal qualities that engender the individual's internal need and tendency to effectively master the real world and find self-expression relative to the outer world. This need may find expression on the mental, motor, or social planes.

By extrovertism/introvertism Eysenck means the features of an individual's interaction with the external environment, in particular with the surrounding social sphere, in other words sociability. Extroverts are drawn to society and follow events around them carefully. The source of their interest and enthusiasms is events in the objective world. They adapt quickly to the surrounding situation and to new people, and are so absorbed in what is happening around them that they often "forget themselves." Introverts are people at the opposite pole. Their interests and enthusiasms are directed to a subjective world. They are withdrawn and inclined to self-analysis and solitude. They have difficulty enduring changes in the environment and adapt poorly in a new collective. The morphophysical substrate of this characteristic is the properties of the frontal reticular complex, which supports extended circulation of stimulation by circular channels. In this case the reticular formation of the brain is the generator and the frontal cortex is the modulator of general activism. This complex assigns the energy, rate, volume, and diversity of an individual's actions.

b. emotionality according to Nebylitsyn — this is the set of qualities that describes the dynamics of the occurrence, course, and cessation of different emotional states. This interpretation of the general characteristic makes it resemble neuroticism according to Eysenck [74] or anxiety according to J. Taylor [75], which are defined by a heightened feeling of personal danger, heightened sensitivity to personal failures and mistakes, dissatisfaction with one's self, attributing mistakes to one's personal qualities, and internal unrest. The substrate of this characteristic is the frontolimbic system. In this case the limbic system is the generator and the frontal cortex is the modulator of the stimulation, which circulates in the circular channels of this system.

In the current phase, we believe, the number of general characteristics should be broadened to at least four, including emotional and regulatory stability, two manifestations of human activity and behavior that have just begun to be studied. Emotional stability is defined as an integrated personal characteristic that is described by the interaction of emotional, volitional, intellectual, and motivational components of individual mental activity to accomplish a goal in a complex emotive situation [76], constancy of mental and motor functions under conditions of emotional influences [77], and the ratio between the results of an individual's activity in a calm state and in an emotional state [78].

We define emotional stability as the optimal version of adaptational biochemical, psychological, and physiological changes taking place under extreme emotional conditions to keep the purposefulness of the individual's behavior and activity at a high level.

The emotional state is purposeful adaptive behavior that occurs as the result of reflection of surrounding reality [79-81]. But when we consider various cases of the influence of emotions on a person's state and activity, we are forced to observe not only the positive regulating role of emotions but also cases of confusion and unpurposeful behavior related to the development of emotional stress. This usually occurs in difficult situations with a significant intensification of emotional stimulation [76, 82]. The well-known Yerkes and Dodson curve reflects the relationship of the influence of the strength of emotional stimulation on activity.

The next general characteristic arises from features of the organism's regulation of reactions. This characteristic reflects individual speed, amplitude, and duration of reactions in response to a particular influence, which ultimately determines the possibility of preserving optimal conditions for organism functioning under changing living conditions. Viewing the organism as a complex self-regulating system [83] and using the terminology of automatic regulation theory we can call this characteristic regulatory stability. It determines the typological features of adaptation mechanisms [34, 85].

Each morphofunctional system that determines the particular and general characteristics of an individual's nervous system (the system of analyzers and system of regulatory complexes) has two levels of self-regulation of behavior: 1 — the lower, genetically conditioned, automatically regulated level (supported by the neuron level of interrelationships); 2 — the higher level, consciously regulated by speech-oriented thinking or speech and subject to educational and environmental influences (supported by the interrelationships of the complex of nerve formations). Each morphofunctional system, and even more each level of a morphofunctional system, can have its own distinctive strength, dynamism, lability, mobility, and equilibrium of the processes of stimulation and inhibition. This is the reason for the difficulty of diagnosis and the large number of combinations of these characteristics, which in turn gives the individual personality its uniqueness.

Let us now consider methods of analyzing the following characteristics of the nervous system.

Dynamism of the process of stimulation (referent indicator — speed of formation of a positive temporary linkage). Measuring the index of the Alpha rhythm in the EEG is an adequate method of analyzing this characteristic. The studies of V. D. Nebylitsyn point to a significant correlation between this quantity and the characteristic being analyzed [71].

L. B. Yermolayeva-Tomina [86, 87] has proposed techniques to analyze dynamism by the nature of changes in the skin galvanic reaction [SGR]. She established a positive correlation between the height of the amplitude of the SGR as a component of the orientation reaction to the first application of a new stimulus and the dynamism of stimulation. In people with high dynamism of stimulation the SGR is extinguished more slowly as the new stimulus is repeated. This same characteristic can be analyzed in an experiment to develop a conditioned SGR (the conditioned signal is a flash of light, and the unconditioned reinforcement is pressing on a reaction button). The presence of the reaction is tested in at least three isolated tests of the light flash as the number of combinations is increased. The indicator of speed of development of this reaction (number of combinations before the appearance of the first conditioned reflex SGR) corresponds to the dynamism of the stimulation process. Study of the assimilation of the rhythm of light signals in the EEG at frequencies 11-20 Hz gives an idea of the dynamism of stimulation: the lower the percentage of assimilation, the greater the dynamism of the stimulation process (the correlation is at the boundaries of significance) [71].

The dynamism of the process of inhibition (referent indicator — speed and ease of formation of different forms of internal inhibition). Investigation of the characteristics of the SGR as a component of the orientation reaction to a new stimulus and the speed of extinguishing a conditioned SGR [87, 88], as well as the features of the EEG and the EEG-reaction of rhythm assimilation [71, 88] are adequate methods of analyzing this characteristic.

A high dynamism of the process of inhibition corresponds to a low amplitude of the SGR and rapid extinguishing of it as the new stimulus is repeated. Low frequency, a high index, and a high total energy of the Alpha rhythm and a high percentage of assimilation of the Theta and Alpha rhythms (to 10 Hz) correlate positively with dynamism of inhibition.

The strength of the nervous system in relation to inhibition (referent indicator — caffeine test). The existence of a high correlation between this property and the threshold of sensory sensations (sensitivity), the type of the spontaneous and induced electrical activity of the cerebral cortex, and the endurance and "noise suppression quality" of the nervous system are used to analyze this characteristic.

The works of B. M. Teplov and his associates established experimentally that a higher threshold of sensory sensations corresponds to a stronger nervous system in relation to stimulation [89, 90]. The existence of this dependence led to the development of a whole series of specific techniques for analyzing the strength of the nervous system: by the threshold of the orientation and reaction to a new stimulus (the stronger the nervous system the higher the threshold will be [71]); and, by changing the threshold of sensory sensitivity during the orientation reaction (a larger increase in the threshold corresponds to a strong nervous system [91, 92]) and after it is extinguished in response to an additional stimulus (decrease in the threshold for a strong nervous system [92]). The reaction to stimuli of growing intensity is very instructive for analyzing the strength of the nervous system [71, 90]. Regardless of the type of reaction (reaction time to a sound or light stimulus, critical frequency of merging of flickers with electrical stimulation of the eye, induction of rhythm in the EEG for a flickering light stimulus), in all cases we encounter the same relationship: the weak nervous system has a larger initial effect and approaches the limit of the particular function more rapidly. The behavior of the strong nervous system is the opposite.

The "gradient of force" technique according to Nebylitsyn is used extensively in practice [71, 78, 93, 94, 95].

The level of strength is determined by the ratio of the average time of the motor reaction (pressing the button) in response to a weak sound stimulus (20-40 db) to the average reaction time to a strong stimulus (90-120 db). More often the sound is taken at a height of 1,000 Hz and reaction time is totalled for 15 stimulations. The evaluations may be done by the angle of inclination of the curve of the relationship of reaction time to intensity of the stimulation (the angle of inclination is greater for a strong nervous system).

As indicated above, the strength of the nervous system may be analyzed also by the type of spontaneous EEG and EEG-reaction of rhythm assimilation. It has been established that a lower total energy of Delta rhythm [96, 97], low induction of the Delta rhythm [96, 97], and a low effect of total induction of rhythm [96-99] correspond to a stronger nervous system. A promising method has been developed by V. S. Klyagin [100], who established a direct significant correlation between the strength of the nervous system and the average values of dispersion of the Alpha rhythm (right hemisphere). In people with a strong nervous system the Alpha rhythm is generally well expressed, variable, and has a high amplitutde.

Attempts have been made to analyze the strength of the nervous system by the time characteristics of a nonspecific slow evoked potential taken from the motor zone of the cortex [101]. It has been established that a test subject with a large time segment between the A and C semiwaves has a stronger nervous system.

The laboratory of V. S. Merlin [102-105] has developed a technique that is widely used at the present time for determining the strength of the nervous system. This technique is based on identifying the degree of endurance of the nervous system. The experiment in this case consists of the following. The subject is told to press a button quickly following a signal, which may be, for example, a sound stimulus (45-90 db). The sound is repeated 75-100 times. The interval between stimuli is 5-15 seconds (the time necessary to restore normal neuron activity after the preceding stimulation). The level of strength is determined by the percentage relationship between the average reaction time of the last 15-20 stimulations and 15-20 stimulations at the start of the experiment (the first five times the button is pressed are not considered because they are still influenced by the subject's orientation reaction). If the average reaction time to the last stimulations if 15-20 percent greater, it means that the subject has a weak nervous system.

V. S. Merlin also developed the method of analyzing strength by the skin galvanic reaction (SGR) [102]. This is the method of extinguishing with reinforcement of a conditioned adaptive SGR. It is based on the ability of nerve cells to endure prolonged concentrated stimulation created by numerous repetitions of a conditioned stimulus. The experiment consists of the following. A sound (conditioned) stimulation (50 db) is given to the test subject. The sound operates in isolation for 10 seconds, and then (after the researcher gives the instruction "Press the button!") for another seven seconds against a reinforcement background (the subject presses the button until the command "Enough!"). Thirty sound stimuli are fed at intervals of 1-1.5 minutes. The SGR is taken from the hand which is not occupied working the button. The strength/weakness indicator based on stimulation is the percentage relationship of the logarithms of the average amplitude of the three SGR's (in millimeters) at the beginning and end of the experiment $(\lg M_1/\lg M_2) \cdot 100$ (the first five SGR's are disregarded to preclude the influence of the orientation reaction). Where the nervous system is stronger the value of this coefficient will be higher. This method is a modification of a method proposed earlier by V. I. Rozhdestvenskaya [106]. She evaluated not the amplitude of the SGR, but rather the conditioned reflex effect on the first and many subsequent repetitions of the conditioned signal with reinforcement. V. I. Rozhdestvenskaya [107] also worked out the induction method of analyzing the strength of a nervous system. It is based on facts that are widely known in the Pavlov school. In the first place, a weak stimulus causes irradiation of stimulation, while a medium stimulus causes concentration and a strong one again causes irradiation. In the second place, caffeine has practically no effect on the focus of stimulation in persons with strong nervous systems, while it greatly intensifies this focus in persons with weak nervous systems.

V. I. Rozhdestvenskaya observed the influence of a supplementary light point stimulus on the threshold of another point testing light stimulus before and after the administration of small and large doses of caffeine. With subjects who have strong nervous systems the administration of both small and medium doses of caffeine changes the shape of the background curves of the influence of the supplementary stimulus on the threshold of the test subject insignificantly. In the case of a weak nervous system a distortion of the influence of the supplementary stimulus is observed under the influence of medium doses of caffeine. Thus, a weak supplementary stimulus (in the initial state causing a lowering of the threshold for the stimulus being tested as the result of irradiation of stimulation from a weak center of stimulation) now evokes an inhibitory effect (as the result of intensification of the focus of stimulation and induction of inhibition to surrounding zones). As the result of an increase in the sensitivity of nerve tissue after administration of the caffeine the average supplementary stimulus acquires the properties of a strong stimulus and as a result the concentration of stimulation (inhibitory effect to the stimulus being tested) is replaced by irradiation (heightening of sensitivity to the test stimulus).

The strength of the nervous system in relation to stimulation may be analyzed as the possibility of withstanding the distracting effect of an outside stimulus (the "external inhibition" method) [108]. The indicator of strength is the relationship of the average times for 15 simple motor reactions to a sound stimulus where there is an outside signal to the average time of 15 reactions where there is no such signal. The sound stimulus (4-5 seconds long) is given every 5-6 seconds, which is about six times a minute. The greater the strength of the nervous system, the lower this ratio will be.

The strength of the nervous system in relation to inhibition. At the present time the adequate methods of analyzing this characteristic in human beings have a limited arsenal of means. In 1963 V. I. Rozhdestvenskaya proposed measuring the effect of lengthening and multiple repetition of a differentiating stimulus on absolute light sensitivity (by analogy with animal experiments) [109]. When the differentiating stimulus is extended or repeated a number of times for people with weak nervous systems in relation to inhibition, the stimulus loses its inhibitory effect and begins to operate like a positive stimulus. But in people with a strong nervous system in relation to inhibition the differentiating stimulus continues to act as an inhibitory stimulus in both cases.

The mobility of nerve processes is the speed of replacement of nerve processes (stimulation and inhibition). There are various adequate techniques of analyzing this characteristic: finding the speed of delaying and following conditioned reflexes [110, 111], the dynamics of the aftereffect (subsequent irradiation and induction) of the stimulus [43, 112, 113, 114, 115, 116, 117]; and, urgent alteration of the signs of inhibitory and positive stimuli after preliminary production of the corresponding conditioned reflexes [43, 110, 118, 119]. However, these methods are not monometric indicators of mobility. Thus, the speed and ease of production of delaying and following reflexes depends not only on mobility but also on the strength of the nervous system and the dynamism of nerve processes [120]. The aftereffects of the stimulus and alteration of the signs of stimuli also depend on the mobility and strength of the nervous system: the weaker the nervous system is, the deeper and longer the aftereffect of the stimulus will be [112, 114, 115]; the stronger the nervous system is, the quicker and more easily the signs of stimuli are altered [110, 118, 119].

The method proposed by N. S. Leytes can serve as an example of analyzing the mobility of nerve processes by the aftereffect of a stimulus [113]. The subject is shown a series of letters on a screen in rapid sequence (roughly one every second). The test subject knows from the instructions that there are three types of letters: positive (after which, for example, a button is to be pressed), negative (after these letters a positive letter should be perceived by the subject without pushing the button, that is, negative + positive letters — "conditioned inhibition"), and indifferent letters. They are shown in random order. By measuring reaction time to a positive signal coming in the immediate vicinity of an inhibitory one (after one, two, or three intervals) and in the background (after at least four intervals) it was established that for people with high mobility of nerve processes the reaction time against the background is very important, while the reaction to a positive signal coming one or two intervals after an inhibitory signal does not reflect the inhibitory effect of the earlier stimulus. People with low mobility of nerve processes show a shorter reaction time against the background; after the inhibitory stimulus reaction time to a positive stimulus coming one, two, or even three intervals later is significantly greater. When measurements are repeated a number of times during one test adaptation may occur (a shortening of reaction time, approaching the background level).

The modification of the above-described method devised by Ye. A. Klimov [43] can serve as an example of analyzing mobility by a special alteration of the stereotype. He substituted colored flashes for the letters. The subject produced a motor reaction only to the red light (R), and was not supposed to react to the blue light (B).

Standard signals were alternated at intervals of five seconds using a scheme of RBBR — 15-second pause — RBBR — 15-second pause — RBBR, and so on (20 times). After the stereotype was reinforced, an alteration of it was undertaken: the subject was supposed to press the button for the blue light and not press the button for the red light (signals continued to be fed in the same pattern).

For subjects with high mobility of nerve processes reaction time decreases quickly during formation of the new habit, but continues to be variable during the tests; with "inert" subjects reaction time decreases slowly, but the degree of variation decreases rapidly. The number of mistakes is also indicative. L. M. Abolin [78] used the percentage relationship of the average latent time of the six reactions after alteration of the stereotype and before it as an indicator of the mobility of nerve processes. A lower value for this ratio corresponds to greater mobility.

<u>Lability of nerve processes — speed of occurrence and cessation of a nerve process</u>. The independence of this characteristic is hypothetical; it may possibly coincide with mobility [89, 121]. A number of indicators have been proposed to analyze the speed parameters of the work of the nervous system [71, 115, 122, 123]: (1) critical frequency of flickers with an intensity of flashes 15 times greater than the individual threshold; (2) speed of restoration of light sensitivity after "lighting up" [possibly, exposure to strong, direct light]; (3) ratio between the thresholds of appearance and disappearance of a spot of light when measuring light sensitivity; (4) adequate optical chronaxie.

It has been established experimentally [124] that these indicators, which initially were adopted on a hypothetical basis as an indicator of the high-speed processes of nervous activity (lability), produce a significant correlation with those characteristics of inducing rhythms in the EEG which many authors believe correspond to the level of lability of the cortical cells of the cerebral cortex [125-127]. This proved the actual existence of lability as an inalienable characteristic of the nervous system.

Work done under the direction of E. A. Golubeva [96] has demonstrated that the lability of nerve processes may be measured by indicators of the total energy of Beta rhythms (the greater the energy, the greater the lability) and assimilation of rhythms in the Beta frequency range (the greater the assimilation, the higher the level of lability).

At the present time many studies propose different EEG indicators as indicators of lability. For example, a significant negative correlation has been established between asymmetry in the lengths of the ascending and descending phases of the EEG at rest and the indicators of induction of high frequencies of stimulation (that is, lability) [128]. The ratios of the energies of the Alpha rhythm with eyes opened and closed and the energy of the Alpha rhythm in the 10-14 Hz range with eyes closed to the same when an Ashner test is conducted have also been proposed as measures of lability [129]. We should also note the determination of lability by the technique of registering the aftereffect in the myogram developed by A. Ya. Kolodnaya and modified by M. K. Akimova [130].

There are two types of self-regulation for the above-listed, so-called primary characteristics of the nervous system: lower, and higher, consciously regulated by speech-oriented thinking. Both levels can have characteristics that distinguish each of them from the primary characteristics and therefore, they require independent study. The methods we have considered deal chiefly with the lower-level primary characteristics.

At the present time a great deal of attention is being devoted to working out methods that analyze higher-level primary characteristics. The speed characteristics of nerve processes at the higher level (speed of thinking processes) can be analyzed using the above-described Eysenck technique [63], as well as the method developed in the laboratory of K. M. Gurevich and V. T. Kozlova [131]. In the latter method the subject develops a thought-speech stereotype (for example, the experimenter names animals and plants and the subject must say "Nyet" ["No"] to every third animal name); then the stereotype is altered (for example, the subject must say "Nyet" to every fifth animal name). The same characteristic can be studied by having the subject make numerical associations in random order within the first 10 numbers. The subject must multiply even numbers by two. Then it can be suggested that this operation be performed with odd numbers. The time which it takes for the subject to make the change and the number of mistakes that the subject makes serve as indicators of the mobility of nerve processes. Similar tests can be made by the technique described by O. N. Luk'yanova and co-authors [52].

The lability of thinking-speech activity can be analyzed by means of the "performance of instructions" and "code" methods [132]. Using the first method the investigator gives the subject instructions: listen to the assignment carefully (the assignment is repeated once, and no questions can be asked), begin performance of the assignment only after the command "Begin," and stop after the command "Stop." The subject works with a set of cards, each of which has a specific assignment. A certain time is allocated for performance of the assignment on each card. At the end of the experiment the number of assignments not completed and done incorrectly is counted, and this is the measure of lability. The "code" test uses a set of cards with different variations of standard symbols. A number between one and 10 corresponds to each symbol and the subject has a decoding table to use during the experiment. The goal of the subject is to assign the appropriate number to the standard symbol as quickly as possible without making mistakes. Subjects who have higher levels of lability do better with this task.

The speed characteristics of thinking-speech activity can also be studied using the A. Ye. Khil'chenko method [132].

Research is underway today on the speed characteristics of specific forms of thinking. The work of Ye. A. Rushkevich and I. D. Golova [133], for example, studies the speed of formation of conditioned reflexes for complex groups of symbolic stimuli taken from mathematical logic. This makes it possible to analyze the characteristics (in particular dynamism) of abstract thinking necessary for successful assimilation of mathematics and mathematical logic.

Thus, we have reviewed some methods that allow study of the characteristics of the nervous system at the highest hierarchical level, at the level of analytic-synthetic activity which characterizes the features of thinking. Following V. D. Nebylitsyn's classification we have reviewed the particular primary characteristics of the nervous system. The particular secondary characteristics are equilibrium (balance), that is, the ratio of each of the above-listed characteristics related to stimulation and inhibitions: balance for strength of nerve processes in relation to stimulation and inhibition, balance for mobility, dynamism, and lability. In principle two types of ratios are possible: independent variation of characteristics where any level of the particular characteristic relative to the process of stimulation may correspond to any level of the same characteristic relative to inhibition (type A), or dependent variation of characteristics where the values of any characteristic for stimulation correspond strictly to a certain value of this characteristic for inhibition (type B, which in turn can be broken down into B_1 — positive dependence, and B_2 — negative dependence).

It has been demonstrated experimentally that an intermediate type of dependence (semi-independence) is possible where one level of a certain characteristic related to stimulation correlates with the same characteristic for inhibition for type A, while another level correlates with type B_1 or B_2.

Analysis of the secondary characteristics is more complex, and there are only a few methodological procedures available today for rapid and precise analysis of them.

Investigation of the balance of nerve processes for dynamism revealed the existence of both type A and type B_2 dependence and semi-independence [71]. The authors of this work believe that the interrelationship of nerve processes for dynamism is accomplished according to type A. In their opinion, the referent indicator of the predominance of the dynamism of the stimulation process over the dynamism of the inhibition process is low values for the Alpha index (no higher than 65 percent) [88], low total energy of the Alpha rhythm [96], and high values for assimilation of frequencies in the 1.5-7 Hz range in comparison with assimilation in other ranges [134].

The opinion concerning the type of relationship among nerve processes according to strength is more clear-cut: any level of strength of the inhibition process may correspond to any level of strength of the inhibition process. This is vividly demonstrated in the study by Ye. F. Melikhova [110], who processed an enormous amount of experimental material from the literature. Works devoted to studying balance for mobility describe relationships of type A [135], B_1 [136], and semi-independence [137].

Thus, we have considered the particular characteristics that describe the work of those branches of the nervous system that are directly involved in receiving primary sensory information, that is, the work of the analyzer systems. It should be remembered that the results of measurement of the particular primary and secondary characteristics for one analyzer may not coincide with the same measured for a different analyzer. In this respect the manifestation of characteristics of the nervous system is partial.

The general characteristics of the nervous system are an integrating indicator of a set of personality traits (not related to direct reception of primary sensory information) which constitute the basis of different types of perception of the world by a person and behavior in different life situations. In addition to working out direct experiments to analyze a particular general characteristic, the investigator searches for correlations between this characteristic and the particular characteristics, and with the physiological parameters of various functional systems. At the beginning of this chapter we cited the classification of general characteristics according to Nebylitsyn. The first of them, general activism (extrovertism/introvertism according to Eysenck, primarily reflects the type of activity of the frontal-reticular complex: to what extent the activism of the reticular formation is expressed, what particular division of it, and how strong are the regulating influences of the cortex. General activism unquestionably depends also on the nature of the primary and secondary particular characteristics of the analyzer systems.

Eyesenck tried to find correlates of extrovertism/introvertism among the particular characteristics of the nervous system by experiment. The findings of his studies were treated in the monograph by V. M. Bleykher and L. S. Burlachuk [138]. There is reason to believe that extrovertism is positively related to the strength of the process of stimulation and to the mobility of nerve processes.

General activism can be analyzed using the Eyesenck questionnaire and modifications of it [74, 139, 140] based on the correlation between this characteristic and the type of behavior in different situations (the questions were written relative to the character of behavior). A modification of the Eyesenck questionnaire could be the L. D. Gissen questionnaire [139], which contains 57 questions: 24 questions determine the level of extrovertism/introvertism, 24 questions analyze the level of neuroticism, and the remaining questions define the degree of authenticity of the answers. The subject's answer must be unequivocal: "yes" or "no."

General activism is related to the individual pace of motor activity, the individual's inclination toward diversity of actions, and the need for activity; it correlates with the expression of the Beta rhythm in the 21-30 Hz range when an EEG is taken from the frontal region [73]. This reflects the ascending influences of the reticular formation. Because of their characteristics extroverts do better with work that requires maximum activism and intensity.

Introverts work better under monotonous conditions, but in such a situation extroverts develop reactive inhibition.

The second general characteristic is emotionality, anxiety, and neuroticism. This characteristic describes features of the emotional background of the individual and is analyzed by means of the questionnaires compiled by Eysenck and Taylor, as well as various modifications of them [141-144]. The indicators of the EEG are used in addition to questionnaires to measure the level of neuroticism. It has been proven experimentally that there is a direct correlation dependence between the expression of this characteristic and Beta activism [145, 146]. A low Alpha index, a high frequency and low amplitude of the Alpha rhythm [147-149], and the existence of periods of desynchronization against a background of a low-amplitude and high-frequency alpha rhythm [150] correspond to a high level of neuroticism.

The relationship between the level of anxiety and indicators of a person's activity and behavior is not always unambiguous. In ordinary situations a heightened level of anxiety promotes more attentive, circumspect, and scrupulous performance of the assigned task [151]. It is customary to consider [144] that in extreme conditions a heightened level of anxiety reduces the effectiveness of action, introducing disorganization into performance of assignment and the purposefulness of behavior. But L. D. Gissen [139, 141] and L. M. Abolin [78] have shown that this dependence is observed only for an extraordinarily high level of anxiety. In other cases a high level of anxiety, as an indicator of positive adaptational mechanisms, strengthens emotional stability and helps achieve good results of activity in extreme situations. Thus, the dependence of the results of activity on the level of anxiety is probably described by the Yerkes-Dodson curve.

The third general characteristic, which is also an integration of a number of personality traits, is emotional stability [9, 76, 77, 78, 152-155]. This is also a multidimensional parameter, and at the present time researchers are trying to find its physiological, mental, and behavioral correlates (for example, see [78]). Emotional stability is determined by many qualities of the individual. It is influenced by both the social and psychophysiological characteristics of the person. Thus, people who have roughly the same level of emotional reactivity reveal differences in emotional stability depending on the level of motivation [76]. Emotional stability also depends on mental characteristics such as the ability to orient oneself quickly and to distribute or concentrate attention, as well as on the speed of thinking. The emotional makeup of the individual, that is, the character (sign and modality) and intensity (depth and duration) of the emotional manifestations typical of a particular person in different situations, exercises a special influence on emotional stability.

L. M. Abolin [78] has established a significant positive correlation between the emotional stability of soccer players and positive intensive emotions. The players who are characterized by intensive negative emotions have low emotional stability in important games (emotionogenic situations).

Emotional stability also depends on such a general characteristic of the personality as anxiety. According to L. M. Abolin [78], a fairly high level of anxiety combines with high emotional stability. The same kind of positive correlation exists between this general property and general activism (or extrovertism). It is apparent that a fairly high level of general activism and anxiety is an expression of the broad capabilities of adaptational mechanisms and promotes emotional stability [78, 139]. This relationship continues to a certain point, after which a rise in the level of these qualities lowers the emotional stability of the individual.

Many studies have found that particular characteristics of the nervous system influence changes in state and activities in extreme situations [36, 37, 78, 95, 156-161]. It has been established that in difficult situations created by the conditions of work themselves (high pace, information overloads) or by accidents, such properties of the nervous system as its strength in relation to stimulation, the balance of nerve processes, lability, and mobility become very important. The relationship between emotional stability and different characteristics of the nervous system is not always unambiguous or significant and depends not only on occupational requirements, but also qualifications and age. L. M. Abolin [78] showed that the emotional stability of young soccer players correlates significantly with the strength of the nervous system relative to stimulation. This dependence is not found in older, more experienced players, but they show a significant correlation between emotional stability and the quality of regulation. This subject is considered in more detail below.

A persistent search is now underway for the physiological correlates of individual emotional stability. The work of Z. P. Turovskaya [161] gives findings that testify to a positive correlation between emotional stability and equilibrium of nerve processes and present an EEG characterization of a balanced individual who is resistant to stress. In the background EEG of such a person, the Alpha and Theta rhythms are usually well expressed, and under stress the indicators of the Alpha and Theta rhythms decrease while the indicators of the Delta rhythm increase slightly. A person who is not resistant to stress (unbalanced) shows a low content for the Alpha and Theta rhythms in the background EEG, and under stress shows an increase in Theta and, especially, Delta activity against a background of reduced Alpha activity.

Various laboratory models of emotional states have been developed to analyze the level of emotional stability. For example, there is the well-known conjugate methodology technique proposed by A. R. Luriya and modified by K. K. Platonov and L. M. Rozet [32]. The technique goes as follows. The test subject must perform a certain action (squeezing a Mareyev capsule with the thumb) under ordinary conditions and in an emotive situation (falling forward onto a soft mat from a "standing" or "kneeling" position on the command "Ready, go!"). Emotional-motor stability is determined by the relationship between results of performing the assignment in an ordinary situation and in a stress situation. The experimental findings almost (85 percent) coincide with a real situation. The ratio of reaction time in a calm state to the time for the same reaction under threatening conditions may be an indicator of emotional stability [78].

Some works give physiological descriptions of the state of test subjects during the period of waiting for unpleasant influences. These correlate with poor

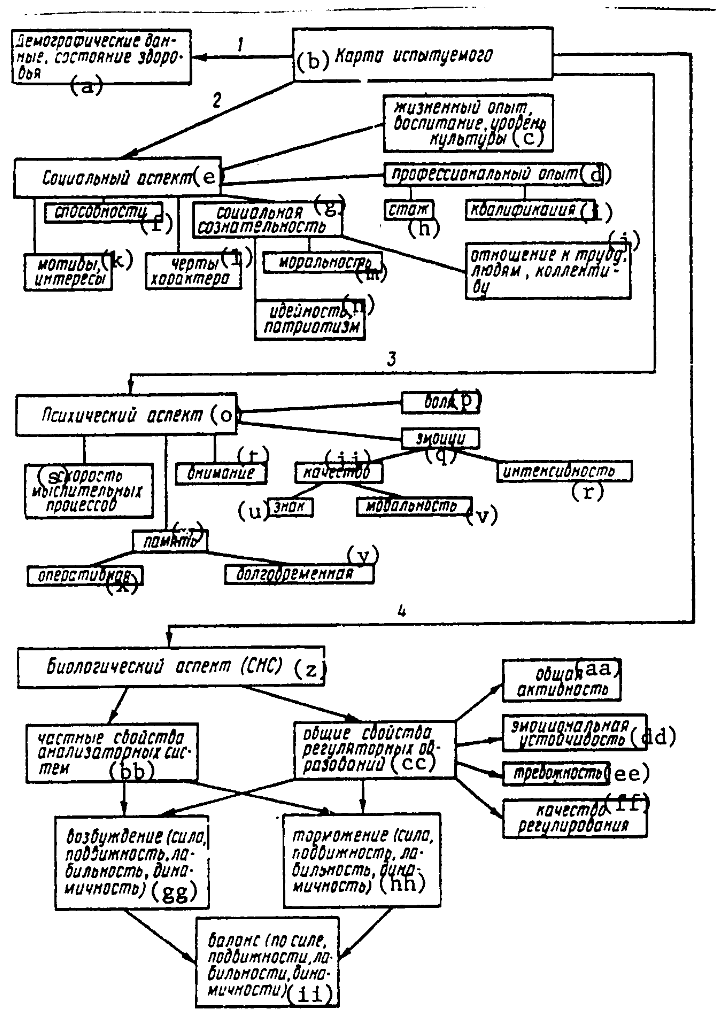


Figure 6. Subject Card

Key:
(a) Demographic Data, State of Health;
(b) Subject Card;
(c) Experience of Life, Upbringing, Cultural Level;
(d) Occupational Experience;
(e) Social Aspect;
(f) Capabilities;
(g) Social Consciousness;
(h) Time in Service;
(i) Qualifications;
(j) Attitude toward Labor, People, the Collective;
(k) Motives, Interests;
(l) Character Traits;
(m) Morality;
(n) Progressive Ideology, Patriotism;
(o) Mental Aspect;
(p) Will;
(q) Emotions;
(r) Intensiveness;
(s) Speed of Thinking Processes;
(t) Attention;
(u) Sign;
(v) Modality;
(w) Memory;
(x) Operational;
(y) Long-Term;
(z) Biological Aspect (Self-Adjusting System)
(aa) General Activism;
(bb) Particular Characteristics of Analyzer Systems;
(cc) General Characteristics of Regulatory Formations;
(dd) Emotional Stability;
(ee) Anxiety;
(ff) Quality of Regulation;
(gg) Stimulation (Strength, Mobility, Lability, Dynamism);
(hh) Inhibition (Strength, Mobility, Lability, Dynamism);
(ii) Balance (by Strength, Mobility, Lability, and Dynamism);
(jj) Quality.

stability under stress (for example, see [162]). Among these correlates are a state of confusion, bradycardia, retardation of EEG frequencies, general hyperhydrosis, arterial hypotension, and a decrease in venous tension.

The fourth general characteristic is regulatory stability. Like the other characteristics, it can be considered on different hierarchical levels. This characteristic can be evaluated at the central nervous system level [84, 85, 163, 164] by analyzing the EEG and evoked potentials. It is clear that this parameter reflects characteristics of the interaction between specific and nonspecific systems of the brain in the perception of deviation in the environment. This quality should also be considered on a different functional level: with the example of change in the parameters of various autonomous reactions. Individual differences in autonomous reactions to any stimulus can be reduced to two types: plastic and inert, areactive and reactive, with low and high autonomous reactivity, or with different levels of emotional reactivity [78, 85, and others]. Such a division reflects the typological characteristics of regulation of autonomous functions, whose highest center is the hypothalamus.

The features of regulatory stability in the sphere of higher nervous activity manifest themselves in regulating one's own actions and behavior b, evaluating a given situation [87, 165, 166].

The indicators of the regulatory stability of different hierarchical levels and morphofunctional systems do not necessarily correlate among themselves, of course. Thus, we have grouped all the many characteristics of the social worldview and thinking and living processes (usually studied separately) in three aspects of manifestation of the human essence: the social, mental, and biological. Figure 6 (previous page) presents a chart of individual characteristics drawn on the basis of studies of these aspects.

The time has now come when we need a generalization of the conceptions of personal characteristics proposed by various researchers. We have proposed our version, which may be far from perfection. Similar attempts are being made by other authors [16].

Chapter 3. Some Aspects of Evaluating the Activity of the Human Operator

Through the entire history of the development of technology and almost to the present day the mutual relations of human beings and machines have been one-sided, involving human adaptation to the machine. During the development of technology machines increasingly look over human motor functions, broadening the human capability for processing matter, while the human being performed preparatory and repair work. The limited range of jobs done in systems of this type, the low speed, and the simplicity of control promoted rapid development of dynamic stereotypes of movements in human beings. When these systems were employed, the primary workload fell to human muscular systems, while psychophysiological characteristics were considered secondary and the designers of machinery did not have to consider them.

The continuing increase in the capacities of machinery and the growing complexity of control processes caused a shift in the human workload to the mental sphere, making increasingly higher demands on such human characteristics as speed and precision of thinking, quickness of reactions, and the like. Finally, in some areas of technology these requirements came very close to the limits of human capabilities under the given conditions. For this reason questions arose concerning matching human and machine characteristics, mutually adapting them. For the human part this meant selection by special criteria, a high level of vocational training for work in a limited class of systems, and so on. For the machine part, it involved refining techniques of representing information applicable to human analyzers, coordinating the input devices of the machine with human effector systems that perform control actions, taking account of human anthropological characteristics, and others [73]. Moreover, it became necessary to transfer a number of human functions to faster and more reliable automatic devices, and at the present time the growing trend is to assign human beings only those technically complex functions involved with selecting system strategies, monitoring the work capability of the system, and the like. Under these conditions the environment, with which human beings had direct contact during labor activity in earlier times, is replaced by a certain information model of the environment [97]. Thus, the most important issues today are no longer human interaction with some particular machine, but rather the more general problems of the interaction of the human being and a certain artificial environment [107].

Until recently, concrete problems of interaction between human beings and machines were solved by separate study of human and machine characteristics [26], whereas the very concept of the "man-machine" system (M-MS) presupposes that it is incorrect, in the general case, to analyze and synthesize such systems on the basis of findings from separate study of the characteristics of the human being and the machine. From this comes the problem of evaluating the work of the M-MS as a whole, despite the qualitative differences among processes taking place in the machine and the accompanying human mental activity. But from the standpoint of systems analysis, which presupposes an adequate breakdown of a complex system into simpler subsystems, the problem of studying human characteristics does not lose its timeliness; on the contrary, it becomes even more significant and meaningful. Representing the operator as a functional element of the M-MS assumes from the standpoint of the systems approach that exhaustive descriptions must be given of all the "inputs" and "outputs" that exist for the work of the given system. Furthermore, this description must be done on the same level (and in the same language) as the description of the entire M-MS. In addition, because this element has memory, its output signals are determined by a function whose independent variables are not merely the input signal, but also a state. In this case memory means both the ability to accumulate information and the inertia of psychophysiological processes.

The sections that follow present a brief survey of work in the field of studying the characteristics of human beings and M-MS's. Proceeding on the basis of our ideas, we will consider in order a description of human activity, a description of the human psychophysiological state, and the evaluation of results of activity.

1. Psychophysiological Prerequisites for the Quality of Human Labor Activity

The methodological foundation for understanding the interrelationship between human activity in a system and the accompanying mental processes is the principle of the unity of the psyche and activity, according to which there exists a special psychophysiological mechanism between the environment and human behavior [141, 188].

From the many approaches that analyze the interdependence of the goal and strategy of human behavior we may single out the following: the "theory of the functional system" [8]; the "physiology of activity of the living organism" [21]; "feedback for forecasting" [106]; the "conception of the set" [219]; the "model of the future" [237]; "plan" [161]; the "nerve structure of the stimulus" [200]; and, the "image" [19].

It is possible to generalize these approaches in an interpretation of any activity from the standpoint of self-regulation of one's own behavior not only at the level of the conscious, but also enlisting other mechanisms [239].

M. D. Mesarovich and co-authors [256] introduce the principle of "satisfactoriness" to explain the nature of interaction among systems in the organism. "Satisfactoriness" is interpreted as follows: "Being subjected to the influence of undesirable disturbances, the organism changes its control so that the basic vital characteristics of its systems remain in a certain satisfactory range as long as the disturbance continues, and any control that brings about this state is preferable for the organism in the given conditions."

Work [125] considers a possible model of the process of self-regulation of behavior by the operator. In the author's opinion, self-regulation involves redistribution by the operator of stress to the performance of particular stages of the activity in conformity with an assessment of the degree of the significance of performing particular stages in the overall structure of the activity. The diagram of self-regulation can be represented in the form of two components connected in series. The first of them relates to heightened energy expenditures to activate the appropriate systems of the organism and includes feedback according to the probability of not achieving the goal. During thinking activity based on past experience images of a higher level of generalization are generated and increase the probability of achieving the goal. Thus, in the first case a more complex task is compensated for by increasing energy expenditures, while in the second case this is accomplished by an intensification of information activity. It may be supposed [170] that self-regulation of behavior by a person involves an empirical determination of the tension of the organism's physiological systems adequate to achieve the results of the activity and meet the required quality criterion.

Work [238] shows that in its interaction with the environment the organism strives to stabilize the parameters of the particular physiological systems in a certain range of their states. The tension of the physiological systems corresponding to this state makes it possible to use the different resources of the organism more economically taking into account the specific features of the activity.

On this level learning can be viewed as the process of acquiring special habits that enable operators to perform their functions with minimum stress.

As a result of the ability to forecast the time of action of stimuli and their properties, the operator can optimize the distribution of stress in different phases of the activity. The characteristics of human forecasting of time and structural characteristics of signals are closely linked to the individual characteristics of rhythmic processes in the organism. For example, the overestimation and underestimation of the same time sequences made by people with heart rates up to 86-102 and 58-64 beats per minute were commensurate with these heart rates [144]. People with a normal pulse rate may deviate in either direction. No relationship has been discovered between the basic rhythmic processes, the frequency of the Alpha rhythm, the rate of heart activity, and frequency of breathing. Variation in signal processing time is linked to the strength of nerve processes. But this condition is inadequate for rhythmic activity [119]. In addition to it the constancy of reactions is influenced by the ongoing functional state and degree of automatism of the activity being carried out, that is, adaptation. The operator's adaptational capabilities can be assessed by a quantitative description of the sensomotor reaction constructed with due regard for the number of signals in a training series [124].

Adaptation to the activity being performed is accompanied by changes in the parameters of physiological indicators. These changes are proportional to the activity being performed. The impossibility of adaptation shows itself in a significant deviation of physiological indicators from background indicators [110]. Brief nerve disturbances related to abrupt changes in the nature of activity are defined as a "state of prostration" [153] which is accompanied by a sharp drop in the effectiveness of activity, all the way to cessation of it. Despite the individual character of these reactions, they are accompanied by relatively singular physiological reactions of different degrees of expression. There is a sharp increase in the variation of cardiac cycles in the direction of retardation (from 84 to 66 beats a minute), followed by a sharp increase in the rate. The amplitude of the skin galvanic reflex grows and high-amplitude slow waves appear in the EEG. The action of nonstationary signals that the operator does not expect causes a state of emotional unstability, which sharply increases the spread of indicators of the quality of activity [184]. Complete operator adaptation takes place in two stages. First the indicators of sensomotor activity stabilize, then the indicators of autonomous functions stabilize. Quantitative evaluations of the processes of restructuring the functioning of the organism applicable to ongoing tasks can be determined by the characteristics of the EKG [34].

Work [206] investigated the adaptation characteristics of the brain in the process of information overload. The methodology of intensive foreign language study was used. Two types of change were observed in the restructuring of the bioelectric activity of the brain in different stages of learning. These stages were clearly linked to the nature of the basic activity of the test subjects.

It may be supposed that multiple repetitions of the conditions of appearance of a signal and performance of a series of actions would not lead to the elimination of thinking operations through the development of "automatism" but rather to developing a higher-level program of actions taking into account the statistical structure of the learning sequence.

Evaluation of the level of training can be constructed taking into account the amount of information which the operator processes in a unit of time [80, 203]. For the case where the number of possible answers by an untrained operator may be large and the probability of selecting alternatives in work is not identical [83], an integrated criterion is obtained by computing the number of cases of correct behavior in response to an indefinite signal and relating this sum to the total number of operator actions for each of the habits being formed.

Work [114] considers the case where operators do not receive information on the quality of their activity. In such conditions as the number of signals in an array that the operator processes increased, the average signal processing time for this array approached a certain range characteristic of the particular operator and signal parameters. The degree of adaptation was determined by the probability of finding processing time in the range of these values.

Work [203] established that there are two components in the structure of a habit: level of training in the procedures and technique of the particular type of activity and operator adaptation to the concrete conditions. The levels of development of these components are measured by different statistical parameters of the initial set of realizations of the process:

1. the mode defines the actual level of training in the habit;

2. the median evaluates the actual habit taking background into account;

3. the arithmetic mean evaluates the effectiveness of the practical action.

As the tests are repeated asymmetry decreases, and therefore it is proposed that this phenomenon be explained on the basis of the following functional relationship:

$$\text{bias} = \frac{\text{level of training}}{\text{adaptation}} \times \text{distractability.}$$

2. Human Functions in Ergatic Systems

There are many different forms of interaction between human beings and technical devices in man-machine systems. The operator can perform a broad range of tasks to support the work capability and operation of such a system. Accordingly, operator activity can be analyzed from different standpoints. In the literature devoted to the problem of the human operator we can identify the following basic areas today: classification of man-machine systems; physiological aspects; and, human interactions with technical devices and development of special mathematical apparatus oriented to describing the functioning of systems of this class.

In work [182] the systems that require human presence (ergatic systems) are classified by a functional characteristic defined by the degree of human participation in the work of the system. Two boundary classes are identified: deterministic systems and probabilistic systems. In deterministic systems the operator can estimate the values of parameters in the future at any time according to a known law of change. In these systems the operator's functions involve servicing various program units. The operator performs preparatory work: repair, adjustment, preparation of programs, and the like. In nondeterministic systems the values of system parameters may be predicted with a certain probability. Therefore, human presence in all stages of its activity is extremely essential. This is owing to the purely human capabilities which determine successful operator activity as a part of the control contour [98]. It is proposed that intermediate classes be ranked by levels of the hierarchy, dynamic properties, form of data representation, and other such features. Work [216], in classifying ergatic systems, uses the following factors as determining: number of persons working in the system; degree of operator participation in the work of the system (in systems of the first type the operator performs the tasks of monitoring, analyzing malfunctions, evaluating work capability and the like; in systems of the second type the operator is directly engaged in control in a tracking mode).

The works of A. I. Gubinskiy (for example, see [157]) classify systems of this type by the following features.

1. By mode of functioning. Depending on the degree of their use at the moment under consideration systems may be in the standby mode, mode of preparation for functioning, and functioning mode. Moreover, there may be one-time preparation and functioning or repeated preparation and functioning.

2. By the role of the human being in them. Systems of the first type are systems in which the operator performs the functions of monitoring and restoring work capability. In systems of the second type the operator works together with the technical units. In systems of the third type the operator works only after a machine malfunction, performing its functions. In systems of the fourth type the operator handles requests only when the machine is loaded with prior requests.

The comprehensive approach, which includes two inseparably linked areas, the static and the dynamic, is used to evaluate the functioning of an ergatic system. Work [181] gives a general description of these areas. In the opinion of the authors, the static component of system state is a set of parameters that describe the properties of the system, while the dynamic component is a set of values of the parameters that describe the processes which take place in the system at certain moments in time. The system-structural approach is used to describe the essential activities performed by the operator [160]. The distinctive features of this approach are clarification of the specific activities of the operator, determining the concrete difficulties that arise during the process of mastering this type of labor activity, the effect of individual characteristics on work indicators, and the like. Realization of the system-structural approach with application to operator tasks involves describing the general structure of operator activity in order to establish the psychological and causal relationships that determine the reliability and efficiency of operator labor [75, 142, 145]. A generalization of psychological findings from the study of operator activity in different branches of industry made it possible to identify the following basic groups of operator-type workers [159]:

1. the technologist-operator, who performs the functions of observation, monitoring, and regulating industrial processes to maintain them within assigned limits;

2. the supervisor-operator, who performs traffic organization tasks;

3. the operator who performs remote control of a mobile or immobile object;

4. the operator who directly controls a mobile object.

A number of researchers try to classify the mental activity of an operator in performing various control tasks. For example, work [79] proposes that operator mental activity be broken into three types: sensory, sensomotor, and logical.

Sensory-type mental activity covers operators who receive information on one channel and transmit it, without conversion, on several channels. The typical example of this type of activity is the work of a person in a communications system. Sensomotor-type mental activity involves processing directive information and outputting results in standard form for the particular process. This type of activity is typical for drivers, pilots, dispatchers, and operators of industrial systems, among others. For the most part, the motor form of labor involves the operator's performance of sequential actions in response to a directive signal or a change in the situation in the system. This type of activity is typical for several stages of pilot activity, for adjustment or preparatory jobs done by an operator, and in other such situations.

During logical-type mental activity operator functions involve receiving and processing information, making decisions, and issuing control actions to the appropriate units of the system. In this case the operator experiences the principal workload during information processing and decision-making. With a limited number of problems to solve operator actions take on features of automatism and this type of activity can be classified with one of the above-listed groups. In actual situations all three types of activity by an operator occur. Therefore, the ratios among the different types within the limits of a selected time interval can be the basis for describing operator activity according to the selected characteristics.

According to work [131], operator functions in an ergatic system can be represented as the realization of three modes of activity. The monitoring mode is characterized by the operator's receiving information on the work of the system. In this case the number of parameters being monitored, their features, the periodicity of monitoring, economic and psychophysiological indicators, and other such factors may be taken into account. The regulation mode presupposes periodic operator intervention in the activity of the machine part to maintain certain parameters or for purposeful change in these parameters according to an assigned program in conformity with control objectives. The control mode involves direct intervention by the operator in the activity of the machine part of the system for the purpose of controlling system parameters. This approach to some extent echoes the ideas presented in work [12] relative to levels of control in a living organism.

At the present time many authors are inclined to interpret man-machine systems as single-channel data processing systems (for example, see [98, 179]). According to this idea operator activity can be represented in the form of a sequence of elementary control cycles consisting of distinct, completed stages. The following stages are identified as the principal ones: receipt of information, processing and decision-making, and issuing control actions. Where necessary these stages can be broken down into more detailed components. For example, work [166] breaks the control cycle down into the following parts:

1. receipt of information — isolating the signal from the information background and determining the message which the signal carries;

2. processing and decision-making — extracting the algorithm for processing this signal from memory, processing with due regard for computation and logical conclusions, and formulating the result (formation of information-instructions);

3. carrying out control actions — searching for a means to realize information-instructions, and realization of the result: issuing information-instructions.

The control cycle is considered to begin at the moment that the operator receives information on a change in the parameters of the process being monitored, and the basis for execution of all stages is the point where these parameters reach or approach the boundaries of permissible values. The total time of realization of the control cycle, including the time of change in controlled parameters, is defined by the signal delay caused by the human being and the hardware.

The quality of operator performance of functions in different phases of signal processing differs. According to figures given in work [222] the largest number of errors (81 percent) made by a pilot comes in the phase of receiving information. The process of visual perception is broken down into several more detailed phases: perception, recognition, and classification [7, 228]. The final goal of this process is to assign the specific object to a certain category [57].

Investigation of the stage of information receiving is based on the dual function of the signal. On the one hand, it is a carrier of information that elicits a certain reaction in the sensory system; on the other hand it is an indicator of the characteristics of the state of the environment or technical units and has a certain meaning to the operator. Therefore, the principal areas of research in this field today involve identifying methods of optimal coding of information by display means [149], study of the psychophysiological characteristics of perception of information by the visual analyzer [187], study of errors occurring when the operator is performing the tasks of discrimination and identification, and investigating the relative sensitivity of different analyzer systems [88]. Because the visual analyzer of the operator of a contemporary control system is heavily loaded, the possibility of converting part of the flow of information for receipt by other analyzers such as the tactile analyzer is under investigation [235].

Another approach to the investigation of these operator functions involves estimating the influence of internal factors on the quality of information receiving by the operator. The individual topological characteristics of the operator's nervous system, ongoing characteristics of functional state, motivation, and level of training are considered the principal ones [229].

Work [79] showed that the signal classified in the stage of information receiving determines the nature of subsequent operator actions. In the opinion of the author, the operator works out a control strategy in the form of operations to make decisions on the situation in the system and necessary techniques to influence it. According to [96], the operator in this case uses a conceptual image model of the situation.

The selection of the necessary signal processing algorithms by the operator is largely determined by the operator's ability to extrapolate future situations. This capability has been studied by many researchers (for example, see [55, 180]). Extensive findings have been made on processing discrete signals [122]. It is observed that the results of predicting depend on many factors related to the probabilistic structure of arrays of signals, motivation, the presence of feedback, and the like. All decisions made by the operator in the process of activity are divided into groups. One of the groups is based on logical deductions that follow from an evaluation of the situation, while the other is confined to selecting decisions worked out earlier. It is not possible to draw a clear boundary line between these groups of decisions because they involve close interaction by the primary and secondary signal systems [108]. Based on the results in work [78], A. A. Krylov [131] supposes that most reactions are transitional between reactions of the first and second types.

A special scale that includes different categories of decisions has been proposed to evaluate the intellectual level of difficulty of a decision.

The stage of operator realization of control actions is carried out today in the form of motor or speech reactions. The basic requirements for the corresponding devices were considered in work [73]. Attempts are being made to use bioelectric signals that arise in the nerve-muscular tissue for these purposes [6]. Raising the efficiency of realization of this stage is closely linked to consideration of the anthropological characteristics of the person [45] and formulating rational methods of coding signal information on the results of activity [40].

3. Objective Methods of Evaluating Operator Work Capability

Evaluating the Quality of Operator Performance in the Stage of Receiving Information

Evaluating the quality of information receiving involves analysis of a number of informative indicators which adequately reflect the influence of "internal factors" on this process [18]. Because most of the information in operator activity comes to the visual analyzer, operational monitoring of its work capability is an important component part of the general problem of monitoring the efficiency of operator activity. The muscle balance of the eyes, the size of the pupil opening, the length of sequential images, the "stability of clear vision," the frequency of eyeblinks, the critical frequency of image merging, the thresholds of electrical stimulatability, reaction time, and other qualities change under the effect of fatigue [28, 99, 127, 183].

Work [118] reviews methods of evaluating the visual work capability of a person. Two classes of criteria for evaluating this type of activity are identified: a priori, and empirical. The class of a priori criteria include criteria in which visual work capability is evaluated indirectly:

1. the optico-physiological criterion (qualitative and quantitative evaluations of visual functions — sharpness of vision, binocularity, and the like);

2. information criterion (carrying capacity of the visual analyzer working under different conditions).

The empirical criteria include the criteria according to which visual work capability is evaluated by the results of performance of a particular type of activity:

1. productivity of labor (volume of work in a unit of time, number of mistakes);

2. operator fatiguability.

The a priori criteria, despite their high prognostic value, involve intervention in operator activity, which significantly limits the possibility of using them for the problems under consideration [207].

With respect to the general problem of evaluating operator work capability to evaluate the quality of information receiving it is necessary to analyze a number of informative indicators that reflect ongoing psychophysiological characteristics of the sensory system. Many investigators have shown that change in the activation of the sensory systems is reflected in the parameters of the EEG, the EKG, the EOG (electrooculogram), the EMG, pulse, and respiration (for example, see [230]).

Work [229] singles out shifts in the indicators of the EEG, EOG, and SGR (skin galvanic reaction) caused by the detection of signals as the activation complex which characterizes the functional state of the operator during signal receiving. It notes the individual quality in selective distribution of activation of those systems which occurs when a signal appears. It is believed that this factor may serve as an indicator of rational expenditure of psychophysiological reserves of the organism in the process of performing this type of activity.

V. I. Myasnikov and I. P. Lebedeva [162] recorded EEG's, EKG's, and EMG's of the muscles of the deep flexor of the fingers of the right hand in the process of information receiving by the operator and identified a direct correlation between the latent period of the response reaction and the expressed orientation reflex.

Work [13] established differences in the process of fatigue of the visual analyzer when working with a mandatory rate of perception and a random rate.

The electrooculogram (EOG) and the biopotentials of the eye movement muscles are an important indicator of the state of the visual analyzer and in large part meet the requirements made for monitored parameters. Recording the EOG makes it possible to obtain many important characteristics of the process of operator receipt and processing of visual information practically without interference to the operator. The main types of eye movements and their physical characteristics are given in [59]. The work of the eye movement apparatus is closely linked to certain functions of operational memory, which determines the preservation of traces from earlier fixations [87]. In this sense eye movement activity in the process of the "information search" is instructive [96]. The essential feature is active identification and conversion of elements of the information field relevant to the problem being solved. In certain stages the information search may be viewed as an independent type of activity that includes ordering objects, identifying useful information by assigned criteria and sorting, recalculation and nonselective retrieval of objects, and so on. These tasks are performed by means of perceptive and mimicking actions which manifest themselves in prolonged fixation of the eyes on particular elements of the information field. Attempts to divide time expenditures into perceptive actions and intellectual actions proper are extremely complicated because work is done in this case with a conceptual image model of the situation formed during the familiarization process [41, 60].

Depending on the nature of tracking movements, eye movement activity is subdivided into three levels [197]. The lowest level reflects imprecise tracking movements, while the middle level is the second type of imprecise tracking movements, and the highest level is precise tracking movements. L. D. Chaynova [230] identifies three levels of activation of the sensory systems depending on the effectiveness of performance of visual activity: the most complex regime, the optimal regime, and the preferable regime. Indicators of the activity and certain objective indicators of the information search process (number of steps, length of fixations, and the EEG and EKG) are used as quantitative characteristics of the regimes.

The frequency of blinking movements is an important characteristic of the reliability of the visual analyzer of an operator. An increase in the frequency of blinking movements may occur as the result of various irritants in the air, abnormal lighting, and the effect of other physical factors [127]. During operator activity this characteristic of the visual analyzer changes mainly as the result of fatigue. According to findings given in work [103], the number of mistaken actions by the operator increases synchronously with increase in the frequency of eyeblinks. A study made by the authors of this book on the frequency of eyeblinks for an operator performing the operation of feeding data to a computer under time deficit conditions showed that the number of mistakes grows as the volume of information processed increases. When the density of the information flow reaching the visual analyzer increases, the area of the EEG decreases, the frequency of the Alpha rhythm rises, and it becomes desynchronized. In this case the energy expenditures in the eye movement system decrease, pulse frequency increases, and slow high-amplitude oscillations occur in the SGR [230]. K. K. Ioseliani and co-authors [112] recorded EEG's (integral activity for five seconds), EOG's (vertical and horizontal components), EKG's, SGR's (amplitude and length of reactions), EMG's (flexors of the fingers of the right hand), electrotensograms, and spoken answers during the process of the operator's search for and recognition of cartographic objects. The results of activity were evaluated by these criteria: recognition time, accuracy and degree of confidence (according to the latent period of the spoken response). The experiments showed that the most sensitive indicators of the complexity of an information search are the ocuologram and its basic characteristics: time of eye movement activity, number of steps, and average length of fixations. In the EEG during intensive activity the Theta rhythm dominated when difficulties appeared and the Beta rhythm dominated when work was done efficiently.

The conditions of activity have a large influence on the visual work capability of the operator. The resolution capability of the eyes declines with an increase in the frequency of vibration. The resonance frequencies 4-5 Hz are particularly sensitive for an operator [58]. P. M. Suvorov [209], who studied the effect of accelerations on the work capability of an operator, observed an intensification of Beta activity in this period without significant shifts in the spectra of the other rhythms; this intensification continues when visual impairments appear. The appearance of a "gray" or "black" shroud in the field of vision is preceded (by 3-10 seconds) by the disappearance of pulse from the vessels of the floor of the auricle or a decline in pressure there to 40 mm merc col. Indicators such as the EEG, EKG, respiration, and the systolic indicator do not change significantly; some indicators also remain unchanged during the period of loss of consciousness.

The parameters of the EEG, which are simple in a computational sense, are used for purposes of diagnosing and monitoring the state of the visual analyzer. Attempts to relate the average values of EEG amplitude and the value of the Alpha index to sensomotor characteristics have produced some results [245]. More promising findings have been obtained by investigating the interrelationship of the form of oscillation with the speed of information processing in the visual-motor system [50].

In work [51] a calculation of the mutual correlation of the average level of asymmetry and average period of the spontaneous EEG and various indicators of sensomotor activity showed that the average period of oscillation is not related to these characteristics. According to the findings of this work the number of mistakes made during a correction test with rings correlates well with the average level of asymmetry of the EEG, but also depends strongly on the motivation of the test subjects.

Another approach to evaluating the visual work capability presupposes the existence of a relationship between oscillations in the pulsation of central neurons and mental processes taking place in microintervals of time [143]. A theoretical calculation of some patterns of visual perception by frequency characteristics of the EEG revealed a direct relationship between the frequency composition of the oscillations of brain structures and typical features of visual images, in particular the information capacity of the images. After working out a frequency model of the neuron, the authors [136-139] obtained a good coincidence of calculated results with experimental results for the time of the sensomotor reaction in a choice situation, for the time limits of perception of a sequence of visual signals, for the minimum time from the moment of the visual effect to the moment of maximum operator readiness to receive subsequent visual stimuli, and for various other characteristics. In our opinion, the experiments confirm the hypothesized relationship between the frequency composition of the EEG and the "spatial frequency" of elements in visual images. This made it possible to use the results of processing evoked potentials to determine accurately which stimuli were perceived by the operator.

Analogous results were obtained by B. Berns, who used a different approach [20]. The patterns detected cannot yet be used to monitor the state of the systems of the operator organism related to receiving information, but there is no doubt of the promise of this approach for these problems.

Evaluating the Quality of Information Processing

Recording and analyzing the EKG is an essential part of monitoring the state of the operator. This is related to the high informational value of the cardiac rhythm for these problems and the methodological simplicity of recording [175, 176]. Work [79] establishes the existence of an almost linear dependence of pulse rate on the amount of information coming to the operator. A number of works have shown change in the variability of the heart rhythm in different stages of mental activity. Thus, work [135] observes that the phases of getting into the work rhythm and active work are accompanied by a decline in the variability of the heart rhythm. When work capability decreases slow waves appear in the EKG and may be used to forecast the work capability of the operator [84]. Findings on oscillatory components of the EKG during prolonged mental activity are given in work [135]. When the intensity of activity grows there is an abrupt increase in the frequency of heart contractions and their variability [30, 195]. Work [247] contains data on the existence of a correlation between the variability of the frequency of the heart rhythm and the number of mistakes made by the operator.

The mathematical expectation and coefficient of variation of pulse frequency were used as the most informative indicators to evaluate psychophysiological tension in work [25]. Maximum efficiency of activity was observed for minimum decreases in the coefficient of variation.

V. A. Dushkov and co-authors [78] recorded the average number of heart contractions and the instantaneous values occurring at each contraction in order to evaluate the effect of mental tension on change in the functional state. They established that the correlation coefficients between time of performance of the assignment and change in pulse were statistically significant, but these indicators are not well protected against individual differences related to motivation, level of training, characteristics of compensatory mechanisms, and the like.

The authors of [44] used a set of eight indicators of the cardiovascular system, including pulse rate, tachooscillographic adrenalin values, and data from phase analysis of the cardiac cycle and stroke volume to distinguish the state of rest and emotional tension caused by waiting for stroke loading. They evaluated informational value by the linear discriminative functions method according to Fisher. Pulse frequency and average adrenalin proved most informative.

According to the results presented in work [236], the average values of the amplitude of the EKG and RR intervals taken at one-minute intervals do not have a reliable correlation. Under physical loading the periods of existence and absence of a correlation during the transitional process occur in regular order which reflects individual characteristics and is preserved regardless of the number of tests.

A generalized indicator characterized by the ratio of the averaged frequency of the background EEG to average amplitude was proposed to evaluate the current functional state of the central nervous system.

A. V. Chubarov and V. V. Petelina [231] showed that it is most convenient to use an inverse relationship to simplify the apparatus in this case. This indicator reflects operator activity in the addition mode very well.

A number of works have noted the tendency for errors to appear when operators who have spent more time on computation multiply pairs of two-digit numbers. In this case the test subjects who normally had a low amplitude for the Alpha rhythm or transformation of the EEG in the unfavorable direction (irregular acute and Theta waves, and low-frequency Alpha rhythm transforming into Theta oscillations of 7 Hz) allowed concealed malfunctions (errors) more frequently.

The Alpha index, the amplitude of the Alpha rhythm of both hemispheres, asymmetry of oscillations, and difference between the ascending and descending wave phases are considered to be psychological indicators that determine the productivity of operator activity. The indicators of asymmetry, amplitude, and frequency of the Alpha rhythm correlate significantly among themselves.

Work [214] notes the existence of a relationship between dispersion of the reaction time to directive signals and the coefficient of opening and closing the eyes (the ratio of the rate of synchronization of biopotentials of the brain to the rate of desynchronization). It is also emphasized that there is an extreme value of this indicator where the efficiency of operator activity is maximal (for the accepted time criterion). Its numerical values are not constant, even for one subject, in different experiments and vary within the limits of a certain range of values. The intensity of a person's activity is reflected by change in certain parameters of the EEG. Thus, it was observed earlier [248] that as tension related to concentration of attention increases, desynchronization (depression) of the Alpha rhythm occurs. In addition, a decrease in the number of spontaneous depressions of the Alpha rhythm has been observed when the probability of the appearance of an expected signal increases. A number of works, however, have also described the opposite phenomenon during mental tension: a rise in the Alpha rhythm. According to the findings of work [198], moderate tension is accompanied by a rise in the integrated capacity of the Alpha rhythm, but a further increase in tension leads to its depression. Investigators attempt to interpret these contradictory findings by considering depression to be the result of directed thinking, while exaltation is viewed as the result of generalized thinking.

Direct differentiation of a person's states by the parameters of the EEG was first presented in work [49]. During analysis of the interrelationships of three EEG readings (from just below the crown, from the back of the head, and from the temple), the author found statistically reliable differences for different types of mental activity. He used the average level of asymmetry of the oscillations of spontaneous activity as the indicator. In later studies using this indicator several types of mental activity were consistently classified, despite individual differences. In certain cases the correct classification of arithmetic counting, squeezing the left wrist, and reproduction was 85, 88, and 70 percent respectively [50]. A similar study with other EEG indicators was done in work [260] to classify five different mental states. In this case the average amplitude of the Alpha rhythm in the crown-back of the head region, the average period in the crown region, coherence in the zone between the back of the head and the crown, and coherence in the zone between the crown and a biopsipital reading sensor selected from a group of 15 indicators were recorded in advance. The average results of classification of states were correct in 62-69 percent of the cases. In the work of A. A. Genkin [51] two types of activity were correctly distinguished by the coefficients of interaction of phase length and correlation of the period and amplitude in 91 percent of the cases.

Recording the EEG during a correction test with circles revealed a significant decline in the average level of asymmetry during periods of skips. In addition, the dispersion of slow oscillations of secondary values of asymmetry in the back-of-the-head and forehead readings increases at the moment of an error.

A number of authors [147, 227] consider the dispersion and mathematical expectation of integrated activity in the zone of the Alpha rhythm to be the most informative parameters in the EEG. The coefficients to distinguish these stages have been established based on the parameters of the distribution laws of the Alpha rhythm for operational rest and in a state of heightened attention. Change in the nature of the distribution law of the background EEG with a change in the person's functional state is also noted in work [169].

Work [65] proposes a method of obtaining a "current index of activity" of the EEG based on computation of the ratio of the low-frequency index to the high-frequency index.

Evaluating Operator Work Capability by Data from Multichannel Recording of Physiologic Indicators

Under actual conditions different types of difficulties may face the operator in different stages of the functioning of an ergatic system, and for this reason the load on the physiological systems of the operator's organism may vary. Therefore, monitoring of the current state of the organism involves all systems related to the performance of operator functions. Evaluation of the current state by analysis of one physiological system is not a reliable technique for this purpose in many cases.

According to work [79], the basic reasons for the need to monitor multiple parameters of state are the following:

a. the significant spread of individual characteristics of operators;

b. the presence in the organism of possibilities of compensating for disruption of the function of one physiological system by means of other systems;

c. the multiple elements of a "functional system" responsible for performance of a particular type of activity, which creates the problem of determining the weakest element in the system at the particular moment;

d. the requirements of predictability of monitoring presuppose an evaluation of reserve work capability. This evaluation can be obtained on the basis of an analysis of the characteristics of specialized structures by preferential processing of information and energy support for the vital activities of the organism.

V. I. Myasnikov and I. P. Lebedeva were among the first to investigate the possibilities of semieffector analysis of the operator's state during the processing of visual information [162].

Work [71] proposes identifying leading and secondary parameters in the set of symptoms that characterizes a certain functional state of the operator. They suggest using weighted ratios of parameters as the basis for automatic diagnosis.

The authors of work [168] recorded EEG's, EKG's, SGR's, and respiration. They found that a rise in the emotional tension of the operator manifested itself in an increase in the amplitude of high-frequency rhythms, the amplitude of the SGR, and increases in the frequency of the EKG and respiration. V. A. Bordov [27] recorded pulse rate, respiration, skin temperature, local perspiration, and a number of biochemical indicators while tension was created by various means. He observes that the most significant changes in all the indicators monitored were observed when performing discontinuous counting at a set pace, distinguishing tonal signals under time deficit conditions, in the case of information redundancy, and with an increasing flow of information. In work [79] while the test subjects performed assignments at a given rate using accounting methodology their EEG's, monopolar right and left frontal readings, EKG's, SGR's, and EMG's were recorded. The results of the experiments showed that during the period of block work in the EEG a maximum frequency shift is observed in the direction of the high-frequency rhythms. A change in the objective indicators of state was noted only for those mistakes of which the operator became aware during moments of complications in the work. The most informative indicators, signaling the approach of a breakdown in work, were the EMG and SGR. The peak values of the EMG for nonworking muscles differed by 300-400 percent from initial values, while for the EKG the difference was 20 percent. Proceeding from this, the authors [79] concluded that there is not an unambiguous correlation between the character of breakdowns in the work of the human operator and their functional nature. Indicators of the dynamics of functional state which precede or accompany the time of an error described a physiological situation fraught with the danger of all kinds of error. The authors of work [90], analyzing the very same experimental material, think that the physiological indicators reflect not the quality of activity, but rather a subjective characterization, tension.

Work [64], investigating the sensomotor reaction with choice under conditions of uncertainty and with a warning signal, recorded a number of physiological indicators simultaneously. In addition, before and after the experiment they measured arterial pressure, analyzed the blood for content of sugar and adrenalin-like substances, and analyzed the urine for corticosteroid content. The greatest changes were found in the SGR, EKG, and biochemical indicators in experiments with uncertainty.

V. S. Genes and V. A. Makotchenko [53] compared the information capacity of 10 different indicators of the adrenal cortex and peripheral blood with carriage of mercury (without signs of intoxication) and with mild mercury intoxication. The most informative indicators tested were those related to the functional test. The results of comprehensive processing made it possible to establish that the information value of the complex is no greater than the information value of the best indicator included in the complex.

Work [213] proposes that the distinct physiological indicators of the dynamics of operator state be joined in groups. Its author believes that change in the intensity of operator activity is reflected above all in change in relations within the groups.

The requirements for parameters subject to monitoring are presented in work [90]. The authors believe that the optimal operator state is zonal in nature, so the work capability of all the systems of the operator's organism cannot be evaluated by separate indicators.

In the opinion of V. V. Kopayev and co-authors [123], the overall effect of the influence of all physiological systems can be represented, when evaluating functional state, in the form of a certain "physiological index." They suggest that for identifying the existence of correlations among particular physiological indicators considering that quantitatively equal components of a physiological index are not always physiologically equivalent, the particular physiological reactions should be integrated into a single expression based on the principle of central nervous regulation of work activity. The authors of [123] believe that a precise evaluation of functional state presupposes the use of criteria for the information value of the particular physiological indicators and sets of symptoms.

Studies of operator activity under real conditions, on trainers, and in laboratory experiments have shown that a uniform qualitative structure of physiological shifts is observed in all cases.

According to the findings of [201], changes in the physiological indicators of operator-type workers (proofreaders, subway engineers, power system supervisors, and air traffic controllers) depends on the volume of information received by the operator, the level of its complexity, and accountability for decisions made. The greatest changes in the EKG (increase in the pulse rate to 130 bits per minute) occur in persons in whom high-frequency rhythms predominate in the EEG.

Work [2] gives a comparative description of physiological changes that occur in operators during monotonous work and tension-filled work. The author shows that the indicators of lability of the visual analyzer and the memory and attention functions decline toward the end of the working shift for an operator engaged in monotonous activities. No deviations on the part of autonomous functions were identified. But during tense activities disruptions occur in the visceral and autonomous spheres [113].

In work [35] the EKG and EMG of the right forearm and SGR were taken for pilots. Growth in the frequency of heart contractions relative to a state of rest, the mathematical expectation, mean quadratic deviations, and envelope of the EMG, and the area of the SGR were used as indicators. Linear discriminant functions were calculated to evaluate information quality. This made it possible to express differences between classes of observations with due regard for linear connections among variables. It was established that the informativeness of particular indicators depends on the type of activity, but the highest information value occurred for evaluation based on a set of indicators.

The authors of work [85] believe that the degree of psychophysiological tension of a pilot is well reflected in the effort of randomly gripping the control wheel. From the results of investigations of flight activity on trainers they determined that in this case the most informative parameters are the SGR, length of cardiac intervals during moments of activation of the SGR, ratio of the length of inhalation to exhalation, and involuntary delays in respiration. Work [86] suggests that pulse frequency, the amount of the pilot's reserve attention, the volume of lung ventilation, and the grip on the control levers should be considered the most informative indicators of a pilot's level of training. An integrated indicator of the quality of flight activity is introduced to evaluate the quality of flying with due regard for psychophysiological reactions. V. G. Denisov and coauthors [74] also propose an indicator of the quality of flight activity that takes into account the criterion function of psychological tension.

Studies using laboratory models under different conditions of activity considered the indicators of the person's state and the quality of activity being performed [133]. The generalized criterion of human functioning took into account the indicators of the quality of activity by specific criteria and change in the functional state of the operator. The EKG, FVD [expansion unknown], skin temperature, adrenalin, EEG, pulse rate, SGR, EOG, and a number of other indicators obtained by special techniques were used for an objective evaluation of state. Among these other indicators were problem-solving by visual observation, evaluation of operational memory, decision-making, types of motor reactions, and solving problems involving maintaining an operational link. In construction of the generalized criterion of efficiency it was presupposed that the nature of the relationship between the quality criterion and indicators of functional state does not change throughout the entire range of changes in conditions of activity. The ongoing values of the quality indicator are determined not by the nature of the relationship, but rather by change in state. For each type of activity the quality indicator was represented in the form of a polynomial of a certain fixed degree from corresponding values of selected psychophysiological indicators. The mathematical apparatus employed was based on the least squares technique and allowed evaluation of the informativeness of selected psychophysiological indicators. Based on the findings obtained the authors of this work conclude that indicators related to evaluation of the quality of activity and indicators of the variability of parameters are most informative. But the information value of the particular physiological indicators is not the same for each type of operator activity.

Work [258] presents a possible approach to evaluating the informativeness of physiological indicators based on the techniques of dispersion analysis.

The contradictory character of shifts in parameters of physiological indicators of operator states, especially when the operator's activity becomes more complex, is noted by many authors [4, 37, 167]. In work [117], the EKG, respiration, time of the pilot's spoken reaction, and flight parameters were recorded in an emergency situation artificially created when the plane was approaching the runaway for a landing. Two types of pilot reactions were found in similar situations. The first type is characterized by an increase in the parameters of all physiological indicators at the moment that the emergency signal is expected and rapid restoration when the problem is removed; the second is characterized by a decline in all indicators at the moment of expectation and more prolonged restoration. Work [210] hypothesizes that such manifestations of individual characteristics are caused by the prevalence of sympathetic or parasympathetic regulation. Work [42] considers operator fatigue during tense activity to be the result of additional mobilization of the organism's internal resources. In connection with this it proposes that the stages of fatigue be classified by certain indicators of the sensomotor reaction.

A number of devices have been proposed to automatically monitor the values of physiological indicators. As standard values they use data on mean statistical norms of these indicators or their background values [71].

The vast biomedical findings received from experimental work are not always subject to adequate mathematical processing. This is primarily because of the lack of sufficiently correct methods of describing a complex object like the human organism. In addition, study of operator activity under real conditions is made more complex by the lack of necessary apparatus for taking and recording many potentially highly informative indicators of work capability. Therefore, the traditional psychophysiological methods which successfully handle the problems of vocational selection are poorly suited in practice for evaluating actual operator work capability.

Psychophysiological Aspects of Operator Reliability

The reliability of performance of functions by an operator is broken down into three types [67]:

1. psychological reliability — reliability in relation to irregular failures (errors) because particular actions are done incorrectly or at the wrong time;

2. physiological reliability — reliability in relation to temporary, regular failures owing to shortage of time or the development of fatigue, injury, stress, and the like;

3. demographic reliability — reliability in relation to ultimate failure (aging, injury with disability, and death).

Work [163] considers operator reliability together with the operator's individual characteristics in light of the doctrine of types of higher nerve activity. From the work characteristics the author singles out those which are based on inborn properties of the operator's nervous system: long-term endurance, endurance in relation to extreme tension, resistance to interference, ability to switch, and the like.

This view has been confirmed in numerous later works (for example, see [69, 152]).

According to the findings of Ye. A. Mileryan [159], psychological study of the structure of operator activity makes it possible to identify several regimes of operator activity in which reliability indicators differ substantially. The optimal and extreme regimes are considered basic. The gradation of regimes is done by indicators of operator activity, and so the questions of operator reliability in these regimes are discussed. A number of authors [53, 95, 202] note the great impact of the individual operator's volitional qualities on reliability indicators. E. V. Bondarev and co-authors [29] believe that operator activity in extreme conditions is characterized by selective redistribution of functional capabilities. In this case the primary activity is done with maximum efficiency, while other functions are performed with gradually decreasing results as psychophysiological resources are exhausted. Some works (for example [251]) cite data to the effect that psychological tests do not reflect change in the psychophysiological capabilities of the operator under these conditions.

Operator activity in extreme conditions caused by various factors is analyzed in works [1, 101, 199, 211, 233, 242, 250]. Work [128] studied operator activity during prolonged waiting for a signal (2-10 minutes). For an objective evaluation of the operator's state they recorded the time of the simple sensomotor reaction, reaction time and number of mistakes in differentiating two light stimuli, time required to solve thinking problems, the monopolar EEG from the back of the head, the SGR, the EKG, the vertical component of the EOG, the RMG [expansion unknown], and eye movements. A relationship between the probability of error when solving thinking problems and changes in physiological indicators was experimentally established. Thus, a decrease of 20-30 percent in frequency of the EEG relative to the background EEG before an assignment is given increases the probability of error. The best results for the sensomotor reaction were obtained against a background of diffuse alertness: a stable Alpha rhythm in the EEG, a constant EKG frequency for the particular operator, a large number of eye movements, and maximum observed value of the SGR. Errors involving skipping signals occurred against a background of a slight decline in the level of alertness: appearance of the Theta rhythm, decline in the frequency of the EKG, lack of the EOG of reactions, and a minimal EKG. The character of errors in operator activity is an important source of information to the operator. Operators correct their activities by the qualitative distribution of such errors. In this case operator motivation has an important influence on shaping the tactics of subsequent behavior [164]. Many works note that regardless of the degree of emotional stability, in all cases operators change their tactics depending on the magnitude and nature of deviations in results received. But according to the findings of [232] during the stages of training and getting into the work rhythm, increasing the completeness of information on the quality of work done does not always have a positive effect on the formation of the required habits. This is because there are two categories of information moving in the feedback channels: (1) information which does not hinder operator adaptation; (2) information which does hinder operator adaptation. The second type is typical for cases when the operator's sensomotor habits are inadequately developed and feedback increases the activation of the corresponding nerve centers.

4. Description of Operator Activity and Evaluation of Its Results

Numerous authors use logical-probabilistic methods to describe operator activity [56, 47]. In this case the algorithm of operator activity is considered as a set of elementary operations to process information and the selected logical conditions that define the order of their performance in performing control tasks. Performance of elementary operations is characterized by average time of execution and probability of errors. The logical conditions may be deterministic and probabilistic; they can also be considered as distinct operations. The time of the logical transition and the probability of error-free performance of the logical transition are used to evaluate these conditions.

In work [92] G. M. Zarakovskiy introduces the coefficients of logical complexity and assignment stereotyping to evaluate concrete operator activity. This approach to describing operator activity is based on the assumption that time expenditures to carry out particular operations in the algorithm of activity have adequately stable statistical features. Work [157] systematizes known data on time expenditures for particular elementary operations (such as reading information from various types of display media, processing time, decision-making, pressing buttons, and the like).

The structural method of describing operator activity [157] involves representing operator functions as distinct completed operations that are joined together depending on concrete conditions into blocks of operations from which the algorithm of operator activity is formed. The advantage of this method is that it permits a preliminary assessment of system reliability because statistical data on the time and quality indicators of performance of particular operations are used. But its significant drawback for practical application is that these data are obtained without reference to the impact of constraints on time of performance of the corresponding operations, which must be taken into account when using logical-probabilistic models.

Information theory methods are somewhat more free of this problem. The first works in this field gave a substantiation of Hick's law [253]. It appeared later, however, that the linear relationship between the amount of information in the stimulus and reaction time is preserved within a limited range of experimental conditions, but the amount of information which a person can process varies widely depending on conditions of activity, age, criteria for evaluation of the quality of activity, and so on [32, 67, 72, 132, 179].

Work [46] showed that in the process of training a person forms an internal model of the environment and conditions of activity and optimizes behavior in conformity with this model. Applicable to the problems of information retrieval, at first the operator groups elements, then devises an internal sequence for processing them, and carries out the required action.

O. K. Tikhomirov and co-authors [217] present findings to the effect that when solving problems of classifying objects the operator first uses heuristic solution techniques, and then gradually makes up more informative tests. In this case operator activity is reduced and may coincide with the optimal algorithm for the given conditions. Other authors also note the increase in the operator's carrying capacity during the process of increasing skills [80, 81, 132]. This process is linked to change in the significance of the information received. Two approaches are being worked out today to evaluate this indicator. One of them involves determining the significance of the information received: the extent to which it promotes achievement of the goal [81]. According to the second approach [126], the significance of the information will be greater when it testifies to a lower probability of achieving the goal. A. Ye. Ol'shannikova [167], studying the activity of highly qualified operators, established that where they worked by the criterion of avoiding all errors in action, reaction time to stimuli of different intensity hardly depended on level of training at all. Her explanation was that the operators monitor their activity extensively.

According to the findings of work [70], the use of pilot monitoring instruments to give the pilot the most significant information on flight parameters does not promote an increase in the pilot's time reserves. The authors believe that the pilot prefers to operate with an internal model of the significance of the information being received.

Work [80] proposes that ongoing reserves of carrying capacity be evaluated by the amount of additional information which the operator is capable of processing while performing the primary activity. Work [166] gives summary findings on operator carrying capacity while performing different operations, but the conditions to which these operations correspond are not stipulated. Works [16, 83] also review probabilistic-information methods of evaluating operator activity.

V. N. Trofimov [218] uses the intensity of the flow of information, an indicator of the speed of creation of "diversity," as the measure of the efficiency of an ergatic system for the tracking regime. In this case the criteria of efficiency are the intensity of the information flow and matching errors.

The following requirements, presented in work [179], may be considered general constraints for information theory techniques:

a. constancy of conditions in which assignments are given;

b. constancy of operator characteristics;

c. the period of signal tracking must be greater than the refractory period of operator reactions;

d. assignments should be similar in complexity, type, and significance.

Work [76] also considers the number of conditions, number of possible solutions, character of the decision algorithm, level of assimilation of the algorithm, and existence or nonexistence of feedback on result of activity as limitations on the operator's carrying capacity when processing information and making decisions.

Despite the heuristic character of human thinking activity, many operator characteristics can be obtained through probabilistic information models of operator activity in the form of mass service systems. In this case the human operator is considered as the service apparatus and the time required to service a request is a random quantity [10, 155]. In this case "requests" mean signals that come from technical units to the operator. The flow of requests is broken down into classes whose characteristics may be regularity of arrival, requirements for precision and reliability of execution (service), priority (order of processing), and so on.

The distribution of request arrival time is found from the algorithm of the system's functioning. The law of distribution of time of request handling is determined experimentally or on a model. The workload on the operator and its boundaries are characterized by the average queue length, waiting time for service, and intensity of service. In this the indicators of the quality of operator activity are the probability of failure and the extent to which results obtained from processing particular signals correspond to the given criteria for processing them.

One possible approach to the application of mass service theory in problems of evaluating operator activity is given in work [115]. In this case the ergatic system is viewed as a mass service system with an input flow consisting of failures of the object. The normal regime for this system's functioning is where the failure is handled immediately after it is reported. The mathematical expression obtained for time of servicing requests and probability of the occurrence of a queue may be used as a preliminary evaluation of the reliability of a control system.

The works of B. A. Smirnov propose that all types of complex human operator activity be represented as sums of particular elementary operations according to procedure, information processing, and implementation of control actions on appropriate units of the machinery. Time expenditures to solve any complex problem without experiment are calculated by means of the hypothesis of the independence or parallel-sequential execution of particular elementary actions with known time expenditures for these operations. A good correspondence between calculated and experimental findings has been shown for the sensomotor reaction. Work [196a] considers the operator as a single-channel mass service system with waiting. The index of the reliability of its functioning is the probability of errors, which includes the following factors:

$$P_{\text{ош}} = \sum_{i=1} P_i \times P_{\text{ош}/i},$$

where P_1 is the probability of overfilling operational memory; P_2 is the probability of occurrence of a time shortage (where operational memory is not overfilled); P_3 is the probability of information overload; and $P_{\text{ош}/i}$ is the conditional probability of occurrence of an error during the processing of algorithm i. In the opinion of the author of this work, given an exponential law of service with parameter M and an elementary input flow with parameter λ, the probability of the existence of queue P_r in the system can be computed by the formula

$$P_r = \left(\frac{\lambda}{M}\right)^r \times \left(1 - \frac{\lambda}{M}\right).$$

When developing various control systems that presuppose the presence of a human operator, a precise quantitative consideration of its characteristics in different regimes of functioning of this class of system is necessary. The apparatus of graph theory [56], sensitivity theory [104], and others [189] may also be used to determine the quantitative characteristics of operator work. From an engineering point of view, the most convenient way to describe operator functioning is the method of equivalent transfer functions [186]. The transfer functions of the human operator may be used to analyze the stability of manual control systems and to determine the constraints imposed by the dynamic range of operator characteristics on the corresponding characteristics of the control object. In the process of designing control systems these data make it possible to evaluate the controllability of the object when it is impossible to use full-scale modeling. In addition, this offers an opportunity to reproduce factors which affect the quality of operator activity but are difficult to evaluate under real conditions.

The essential feature of this technique is that the characteristics of the operator performing the role of a link in the control system are described by a certain linear transfer function. The part of operator reactions that does not correspond to this transfer function is represented in the form of interference applied at the same point as the operator output. If the interference is commensurate with the magnitude of the usable signal corresponding to the transfer function, the function is subject to further adjustment. In the general case, the transfer function of the operator has this form

$$W_p(S) = \frac{K_p M(S)}{N(S)} e^{-S\tau},$$

where K_p is the coefficient of intensification; τ is the delay time of the reaction (0.13-0.2 seconds); M(S) and N(S) are polynomials whose coefficients are determined by the concrete conditions of the problems being solved.

In the elementary case when interpreting this class of systems in the form of a single-contour tracking system, the operator receives an error signal and produces the control actions, attempting to nullify the matching error. The dependence of the parameters of the transfer function on the form, spectrum, and range of control signals and the dynamics of the control elements is investigated in work [244]. It is an important result to establish the fact that the type of operator transfer functions obtained in concrete systems is applicable to a restricted class of systems. Operator transfer functions, while meeting the requirements of preliminary investigation of ergatic systems, have limited capabilities in those cases where precise evaluation is required.

The limitations presented in work [240] can be considered the principal shortcomings of models in this class. In the opinion of the author, the most significant shortcomings are the following:

1. Linear analog models cannot have at the output frequencies which are not present in the input signal;

2. These models cannot interpret experimental facts which testify that the operator in many cases acts discretely;

3. They do not consider the ability of operators to adjust their behavior in conformity with an evaluation of the probabilistic structure of the arrays of incoming signals.

Work [259] has proposed a pulsed model of the operator to eliminate the shortcomings of linear analog models. This model includes a linear continuous part and a pulsed element in the form of a periodically operating key. The linear part of the model consists of a corrected linear transfer function and a shaping circuit which is an extrapolator that constructs the function of the input signal in time based on information obtained at the moment that the key is closed. This type of model describes operator actions very well using transfer functions. But it is poorly suited for describing multichannel systems. As a rule, operator actions are linked to the results of processing information that arrives by different channels. These may be scalar instruments, digital indicators, sound and optical signal devices, and the like. A model of this type is based on the assumption that the operator is for the most part a single-channel regulator who switches among different controlled contours. The model permits evaluation of many important operator parameters related to reading information. Senders [259] used this model to predict the rate at which an operator would read instrument readings and obtained a good correspondence. The basic ideas realized in his model have been confirmed in many works by other authors [125]. Situations are possible in operator activity where the operator acts as several regulators, controlling several variables [113]. In this case each parameter has its own contour of regulation. Preferable conditions for the use of types of models to describe operator activity in a multichannel system still need careful investigation.

Work [172] proposes that instead of conventional operator transfer functions generalized work characteristics that give functional descriptions of the parameters of the input signal and processing algorithms be used.

Discrete models of the human operator give an adequate representation to frequencies of 2 Hz (analog 1 Hz). The spectrum of output quantities of discrete models of the human operator corresponds better with experimental data [174].

Adaptive models of the human operator are presently in the development stage. But certain successes have already been achieved in this area [15].

The general drawback of the purely technical approach to describing the functioning of the operator is that it does not adequately consider the unique character of information processing by a human being. Such features of the functioning of the human element as the effect of motivational aspects on indicators of activity, the use of personal experience, and the existence of vast compensatory capabilities raise the challenge of working out a special mathematical apparatus to evaluate the reliability and efficiency of composite man-machine systems.

Comprehensive Methods of Describing Operator Activity

Methods of this type attempt to combine a strict formalized description of purposeful activities by a person solving various applied problems with natural science data on the human being as a biological system with an individual prior history, individual characteristics, and an individual current state, The indicators of operator activity are viewed as a result of a certain "integrated" state of the man-machine system [43, 165, 221].

The simulation modeling technique is most highly developed at the present time [94]. To obtain preliminary evaluations of the reliability of complex human-machinery systems the authors of this work use the techniques and data of reliability theory, mass service theory and human factors engineering. The simulation modeling technique, which considers the technical specifications of the devices used, the structure of operator activity, the parameters of the internal states of operators, and their impact on the quality of activity, makes it possible to obtain average characterization of system efficiency with due regard for psychosocial factors (emotional state of operators, motivation, teamwork in crews, and the like) in the stage of system design. The drawback of the method is the averaged character of the resulting descriptions, which makes it difficult to consider the impact of individual data on the quality of group activity. In addition, the psychological structure of the group of operators (leaders, followers, theoreticians, and the like) is not adequately taken into account.

The operations psychology method [47] is based on a consideration of data on the contentual aspect of psychophysiological processes realized in actions and psychological operations. It is based on the following propositions:

a. The breakdown of activity is done by dividing the structure of operator activity into standard actions for which initial values of time and reliability of performance are obtained;

b. When synthesizing the structure of activity consideration is given to the influence of particular types of tension on the integrated indicators of activity and to the mutual influence of particular actions;

c. When calculating the reliability of performance of particular operations and groups of them it is assumed that human beings can monitor their actions with more than the afferent system. In this case, self-monitoring of results obtained is specific in nature.

The method developed in the works of V. V. Pavlov is a promising approach to describing the characteristics of ergatic systems. In this case the man-machine complex is viewed as an "ergatic organism" which has the following basic features:

a. functional homeostasis, directed to solving the profoundly technological problems of self-preservation;

b. the principle of minimum interaction, which means that operators in all cases try to organize their work to obtain the maximum efficiency of the entire system with minimum tension;

c. the principle of functional compatibility, according to which the functional capabilities of the operator included in a certain way in a closed system must permit purposeful actions by the entire system. The method of nonlinear invariance and autonomism proposed by the author of work [170] is used as the mathematical apparatus. The calculation of a space "ergatic organism" done by this method in work [171] shows that the method already has vast potential in its contemporary level of development.

The integrated approach to evaluating the efficiency of ergatic systems is elaborated in [172, 181]. The authors of these works consider the integrated states of man-machine system and conclude that in the particular case interaction of the human operator and technical devices is so strongly manifested that it is practically impossible to evaluate them separately. Therefore, they pose the problem of developing a branch of reliability theory applicable to the evaluation of such systems.

Numerous investigators try to perform factor analysis of the influence of different environmental parameters on indicators of the functional state of the operator.

Work [255] describes a model of operator stress. The input parameters of the model are temperature, acceleration, vibration, motivation, training, and complexity of the task; the output parameters are time constants, dispersion of the noise of the motor reaction, and dispersion of the noise of observations. The identification of the model according to experimental data was done on the basis of the principle of maximum probability relative to the vector of state.

Development of integrated methods of describing operator activity is one of the problems of the swiftly developing science of ergonomics. The first results obtained in this area synthesize data from the natural sciences with an adequately correct use of mathematical methods to analyze them. This makes it possible to suppose that analysis of all elements of an ergatic system from a uniform standpoint is the most promising approach.

Tension of Operator Activity

The concept of "tension" [napryazhennost'], which is used as one of the evaluators of operator activity, does not have a clearcut unambiguous definition today.

A. Sidzhel and Dzh. Vol'f [191] draw a parallel between tension as an indicator of the psychophysiological state of the operator and the time resources that the operator has. In their interpretation tension is the emotional state of the operator before solving subproblem i, which is computed according to the formula

$$M = \frac{\overline{T}_i^E}{T - T_i^u} \geqslant 1,$$

where M is the indicator of tension; $\overline{T}_i^e$ is the average time available to perform all remaining significant and insignificant tasks on the assumption that the operator makes no mistakes; P_I^u is the total time used to solve preceding problems; T is the total time allocated for problem-solving.

It is easy to see that the average time of problem-solving, when used to evaluate tension, does not reflect the actual psychophysiological state of the operator, in other words, the actual level of tension reached at the moment that signal i is processed.

In works [215, 216] the term tension of the ergatic system is used for a state characterized by identification of the processes circulating in it under the influence of external factors. The authors distinguish two types of tension: Q-tension, which is the state of a system to which it switches under the influence of physical factors (vibration, noise, illumination, and the like). The operation of these factors disturbs the interaction of particular machine units and increases the probability of failure, which increases the load on the operator. The second type is S-tension, which is the state of the system caused by human reaction to the occurrence of a time shortage. The quantitative measure of the second type of tension is determined by the formula given above.

Many authors describe the measure of difficulty of conversions done by the operator with a signal in terms of the time during which the operator performs functions with a given level of accuracy. The quantity inverse to the mathematical expectation of time of trouble-free operator work in an ergatic system is defined in this case as tension. It is considered expedient to represent this quantity in two components, deterministic and random, which refer respectively to the mathematical expectation and dispersion of this indicator. The dependence of tension on precision of performance of the algorithm of signal processing and their complexity is nonlinear in nature, and several extremes of tension are observed for different combinations of these parameters.

V. V. Pavlov [171] believes that tension is a measure of difficulty in operator performance of functional conversions on a signal, quantitatively equal to the average time of existence of the quasistable state of the system.

The authors of work [23] believe that the degree of operator tension may be defined as the ratio between the number of unfulfilled assignments and the time remaining to fulfill them. Some investigators try to evaluate the tension of operator activity by the results of processing psychophysiological indicators of operator state and the results of operator activity (for example, see [101]).

In work [47] the types of tension are subdivided into specific, nonspecific, and specific pace tension. The coefficients of the influence of these types of tension on the qualitity-time indicators of activity presented by the authors were obtained on the basis of their own findings and data in the literature using a point scale and converting the points to percentages.

Works [74, 257] find the numerical values of psychophysiological tension from a criterion function determined by the deviation of selected physiological indicators relative to background value taking into account the weights of the particular indicators.

The authors of works [116, 208] interpret growth in tension as a copmensatory intensification of "autonomous support" against a background of declining capacities for higher nerve activity. With this approach tension is considered a measure of human energy expenditures in the process of labor activity.

B. A. Smirnov [196a] gives an evaluation of operator tension taking into account conditions of operator activity. He believes that the primary factors that promote growth in tension are the load on the operator, overfilling the operator's operational memory, the existence of a service queue and a time shortage.

It seems to us that the approaches considered above try to invest the concept of "tension" with both the meaning of an indicator of the economic characteristics of operator activity (precision, time, reliability, and the like) and at the same time indicators of the measure of difficulty of the activity for the particular persons. It seems to us that for convenience in analyzing operator activity a distinction should be made between tension ["napryazhennost'"] as an indicator of the complexity of the activity and stress ["napryazheniye"] as an indicator of the changes in the functioning of the physiological systems of the operator organism that occur in this case.

State of the Operator

Because the organism represents a complex hierarchical system, there is good reason to use the apparatus of systems theory to describe its functioning. But the concept in systems theory that interests us does not have a clearcut, unambiguous definition. Thus, work [5] uses the term "state of the system" to refer to a set of existing characteristics which the system has at the moment under consideration. In work [36] state is defined as an ordered set of coordinates of the system in a configured space whose dimensionality coincides with the number of its degrees of freedom. Numerous authors [151, 156] consider the state of a system to be a certain instruction for conversion of input signals to output signals that meets definite requirements. In other sciences which use this concept, for example physics, the method of its definition depends on the level of consideration of a dynamic system. The macroscopic level makes it possible to analyze integrated characteristics of an object which are formed by the parameters of the particular components of which the given object is composed. In this case the state of the object means the current value of these integrated characteristics. At the microscopic level state is defined as a description of these components which depends, in turn, on the nature of their interaction within the limits of the volume under consideration. In both cases the term "state" describes the instantaneous values of the parameters of the object under consideration [134].

We intuitively understand the concept of the state of a human being to be some kind of characterization of the processes taking place in the person's organism. A precise definition of the psychophysiological state of a person involves numerous difficulties. The main ones result from the lack of techniques for a clearcut definition of the levels of functioning of the physiological systems of the organism [226]. The divergence of opinions on this issue relates chiefly to defining the norm for an organism. Some investigators assert that it is not possible in principle to give an exact definition of the concept of the "norm" because it is a purely abstract concept without physiological meaning.

Work [79] proposes that the norm be defined as the range of changes in physiological indicators within which the organism maintains optimal vital activity for the given conditions. In the opinion of its author, in relation to operator activity the norm restricts the range of the organism's compensatory capabilities which defines the optimal functional state for the given activity.

Many authors take the term "psychophysiological state" of the operator to refer to a certain variable that depends on the values of the indicators of functioning of the physiological systems of the person's organism. Thus, in work [148] the current psychophysiological state is interpreted as a multidimensional vector for which the values of a set of physiological indicators are taken as coordinates.

In work [52] the state of the operator is considered a function depending on neurophysiological phenomena in the organism and on external factors that influence the organism. The state itself is characterized by a certain range of stable values of the multidimensional vector; the axes of its coordinates correspond to the selected indicators. The authors of this work believe that it is most expedient to use the apparatus of image recognition theory to diagnose the state of the operator. They mention the following factors which make this task significantly more complex:

a. the variability of the responding reaction even with the same subject;

b. the similarity of the reaction with significantly different states;

c. the variability of the reaction among different persons;

d. the relationship between characteristics of the reaction and the phase of oscillatory processes in physiological systems.

V. G. Denisov and co-authors [74] define the current functional state of the operator on the basis of an analysis of the modified function of the cardiac rhythm, which is a Euclidian norm of the initial level and a derivative of the frequency of heart contractions. They believe that the influence of the organization of activity on indicators of operator efficiency can be evaluated by these parameters of the cardiac rhythm.

Such contradictory definitions of the state of the operator are a result, in our opinion, of the formalistic application of the techniques of medical diagnosis to the problems of operator activity. But with the contemporary level of our knowledge on the nature of mental processes we cannot consider a change in the parameters of the indicators of the functioning of physiological systems of the operator's organism isolated from the essential features of the activity being performed by the operator. This is because various deviations in the state of the operator are primarily the result of adaptive reactions to situations in the system of which the operator is an element. The flow of information received by the operator becomes unobserved from the moment it enters the human sensory systems. Therefore, when considering its impact on operator characteristics the observer must be guided entirely by signals circulating outside the operator and by certain objective indicators of the operator's state.

Thus, the "state of the operator" may be viewed as an integrated description of operator stress and the tension of operator activity.

Optimal Working Stress on the Operator

Evaluation of the efficiency of operator activity on the psychophysiological plane involves a determination of the optimal stress on the physiological systems of the human organism while performing operator functions [89]. This problem was first considered by Yerkes and Dodson (1908). They noted that a person must maintain a definite function of the physiological systems in order to attain the best results in any form of activity.

The concept of the "optimum of a physiological process" was proposed by N. Ye. Vvedenskiy [39], but he referred to the strength of the stimulus, not to the physiological process itself.

Works by contemporary authors contain information on particular properties of optimal physiological processes obtained on isolated fibers, in the study of the secretory and motor systems of humans and animals [226], and in study of the full organism. But available findings are inadequate to solve the practical problems of evaluating the integrated efficiency of operator activity.

In reality, these questions today are decided by means of searching for empirical relationships among working conditions, individual characteristics, and indicators of the person's activity [109]. The activity of the human operator in processing signals arriving at certain time intervals has been most fully investigated in this respect. In this case the indicators of activity are usually determined by criteria of the precision and length of the process of processing incoming assignments [157]. The last criterion can be given in the form of a period of tracking assignments within which the operator distributes time expendutures independently for particular operations in the processing algorithms. Accordingly, the activity of the operator can be considered as fulfillment of assignments at the natural pace and at a forced pace [146]. Based on this monotonocity is divided into two types [11, 100].

1. Operator activity in an unchanging situation with passive observation of the process;

2. Operator activity at a high pace with repetition of the same actions.

In the first case the main factor of tension is related to the need to maintain at all times a higher level of activity without the toning effect of afferent stimuli; in the second the main factor is the high level of the local load.

Work [42] gives data on results of observations of change in work capability for different types of occupational activities. In jobs with low stress and short duration working procedures are carried out on the basis of dynamic production stereotypes. Later, as tension grows, continuation of the work is possible only by additional mobilization of internal resources.

Opinions differ on the usefulness of assigning a certain type of time criterion. Some authors prefer work at a forced pace, while others consider it advisable to organize people's activities so that they themselves set the pace. According to the findings given in work [146], special experiments that modeled activity in both regimes identified a significant decline in operator stress when switching from an assigned pace to one they could regulate themselves. After a certain time of activity under these conditions 95 percent of the test subjects showed a desire to step up the pace.

S. T. Sosnovskaya [204] investigated operator activity, including 26 motor operations (throwing switches on and off, pressing buttons and the like) and information retrieval and tracking at different assigned paces. The highest quality indicators were achieved for work at an average pace.

It has been shown that the maximum possible pace of a person's activity is determined by adding the latent period to the response time. Systematic errors begin to appear when this quantity exceeds the period of signal tracking.

Applied to the complex reaction of choosing at a forced pace, work [3] has established that there is a positive relationship between initial and final results. If the quality criterion of activity is given in the form of achieving a uniform pace, the activity of the slower operators (according to initial tests) in the final phase is characterized by a sharp increase in the number of mistaken actions and a refusal to continue the activity. McNemar [254] noted that drill does not lessen the genetic influence on the speed potential of a person.

To select the optimal load for work on a conveyor it has been proposed [198] to compute the load at the ratio of the averaged least time of performance of the operation based on stopwatch results to the average arithmetic time. In this case the variants with the lowest values often coincide with the minimum values obtained in special tests.

When processing discrete signals one of the indicators of completion of the process of training and adaptation to the given type of activity is rhythmic reaction to incoming signals [121, 234].

According to the findings of [135], when rhythm is disrupted erroneous actions related to uneven distribution of stress occur. With rhythmic action if errors are made, they are highly stable in time and frequency.

Work [251] established that when signals come to the operator at different periods, the processing and tracking time for them are inversely related. This relationship is disrupted only through the action of interference that causes competition between stimuli. The stability of processing time for rhythmic signals may occur through compensation for the functions of a weak element by means of other systems [81].

A. V. Levshinova [140] gives experimental results on modeling typical visual and motor functions of a dispatcher, carried out with a steady increase in the pace of activity. The physiological indicators (EEG from the back of the head, internal speech — taking an ENG in the upper lip region, the EOG — horizontal and vertical components, and EMG's of the general extensor, the general flexor, and the extensor of the right thumb) had the same high cross-correlation given functional comfort and in other regimes, but in the opinion of the author this corresponded to different levels of activity for the systems tested.

Efficiency of the Human Operator's Activity

The contemporary interpretation of the efficiency of operator activity is presented most thoroughly in work [181], where the conclusion is drawn that "'efficiency of operator activity' should be taken to mean the ability to perform assigned tasks in a timely and precise manner within the assigned time (reliably) and with minimum expenditures of efforts, energy, and materials."

With this approach the concept of the efficiency of human activity in a control system has two components: efficient performance of assigned tasks and efficient use of reserves, which encompasses both material-energy reserves of the system and the psychophysiological reserves of operators themselves.

At the present time operator activity is being studied in several closely related fields concerned chiefly with evaluating one of the components of "integrated efficiency."

Natural science techniques that study human labor activity are being enlisted to evaluate the efficiency of use of the psychophysiological reserves of the operator's organism [92]. To evaluate the quality indicators of operator activity as an element of the control system, well-developed methods for evaluating analagous characteristics in technical devices are employed.

Despite the qualitative difference between processes taking place in a machine that is processing information and in human mental activity, many indicators of their functioning can be defined from the same standpoint [68]. Because the operator is viewed as an element of the control system, there is every reason to use the methods of formalized description of dynamic objects applied in the corresponding fields of engineering to evaluate operator functioning.

The term "efficiency of a technical system" ordinarily means a quantitative evaluation of the results of its use under concrete conditions [9]. The different schools of analysis of the efficiency of technical systems are basically linked to evaluating their technical or economic indicators [38, 190]. The concept of "reliability" is used to evaluate the technical state of a system and its work capability in every possible state. A generalized indicator of the technical efficiency of a system can be obtained from this expression [48]

$$\bar{E} = \sum_{i=1}^{n} E_i P_i,$$

where E_i is a particular indicator of efficiency; P_i is the reliability of the system in each possible working state; n is the number of possible working states.

With a purely technical approach to the evaluation of operator activity, its efficiency is characterized by operator productivity in different regimes of system work. Thus, work [92] defines the efficiency of human operators by the number of operations which they can perform according to a definite algorithm, in a unit of time, under given working conditions.

A. I. Gubinskiy and co-authors [66-68] have proposed, by analogy with technical systems, that a distinction be made between ideal and actual operator efficiency. Real efficiency is measured by multiplying ideal efficiency times the probability of trouble-free work.

Work [224] reviews the influence of the specific features of functioning of the human element on actual efficiency. Its author believes that the indicator of real operator efficiency should include an evaluation of the operator's heuristic capabilities, the parameters of the environment and technical units, the length of time in which the operator performs functions, and so on.

Work [66] has investigated the effect of failures on the indicators of the efficiency of receiving and processing information and issuing control actions.

Some features of the functioning of the human element in a system, related to the influence of motivational aspects on indicators of activity, the use of personal experience, and the existence of vast compensatory capabilities in human beings, impose certain limitations on the range of use of technical methods for evaluating and forecasting operator activity.

Indicators of the Quality of Operator Activity

According to work [18], any human activity in a system may be reduced to these four stages:

1. search for and decoding of information;
2. evaluation of information and identification of informative features;

3. forming a conceptual model and making a decision;

4. practical realization of the decision that was made.

In the general case, considering the accepted definition of efficiency of operator activity, we may consider two criteria systems of quality indicators of the performance of their functions by operators. The first system is a set of time, precision, and reliability characteristics, while the second considers the efficiency with which the available psychophysiological reserves of the organism are used [155].

A number of works [33, 120, 157] include the following basic components in evaluations of the quality of activity:

1. indicators of precision, specifically:
   a. current error;
   b. average error;
   c. integral error;

2. time indicators:
   a. latent period;
   b. motor reaction time;
   c. time signal is held at given level;
   d. full time for processing incoming information;

3. information indicators:
   a. amount of information processed;
   b. quality of information processing.

A number of authors think that a generalized quality criterion for activity can be formulated by combining particular criteria with different weight factors that take account of the distinctive characteristics of the particular type of operator activity [228].

To evaluate the efficiency of activity investigators use data on the output characteristics of the system, for example economic indicators, and data on the functioning of the physiological systems of the operator's organism during the performance of the assignments. The indicators of bioelectric activity of different physiological systems or the results of solving test problems are used to evaluate the psychophysiological reserves of the organism [111].

The indicators of quality of operator performance of functions are usually evaluated on the basis of a classification of the particular type of activity. The evaluation uses concrete criteria adopted for the particular type of system. In special cases where difficulties arise with evaluation of the predominant type of activity, it is suggested that efficiency be evaluated by the most complex algorithm of activity encountered in the particular system [18].

Work [139] reviews the criteria for evaluating the quality of operator activity in controlling a spacecraft. It singles out particular criteria that allow consideration of different types of mistakes made during flying, and identifies the main criterion as the area of the intersection of the particular and supplemmentary indicators.

Despite significant differences among the many technical criteria used to evaluate particular cases of operator activity, most of them can be reduced to two types: precision indicators and speed indicators. In some cases the criterion of maximum speed is not specially stipulated, but can be an implicit part of the precision criterion. This is especially typical for work under conditions of limited information processing time.

Work [157] analyzed the relationship between these criteria. It established existence of an analytic dependence between indicators of operator activity received according to the criteria of precision and speed. Work [205] presents averaged figures on indicators of precision of operator performance of particular operations and combined indicators of precision and speed.

Generalized quality criteria are usually oriented to evaluation of concrete activity. Various indicators may be used here depending on the purpose of the investigation. For example, the number of error-free read-outs in a unit of time was used in work [68] to evaluate the efficiency of information receiving. V. N. Trofimov proposed that functional efficiency be used to evaluate activity when an operator is working in tracking regimes. By functional efficiency he means the ability of an ergatic system to achieve its goal by the most rational means [218]. Work [31] proposed a criterion for evaluating the effect of training on indicators of activity. Works [62, 129] also used their own criteria.

Evaluating the Reliability of the Human Operator

Reliability characterizes the capability of a system or element to perform its functions in a given time. Changes in the system that cause partial or complete loss of work capability are defined as failures [14, 105].

Work [67] proposes that the criteria for evaluating the reliability of technical equipment which may be used with application to the problems of human factors engineering be put into three groups:

1. criteria of no-failure operation;
2. criteria of restorability;
3. readiness criteria.

These criteria include the following basic indicators:

- probability of no-failure operation;
- average time of no-failure operation;
- frequency of failure;
- average restoration time;
- readiness factor.

Quantitatively, reliability is expressed as the numerical value of the probability of no-failure operator work under definite conditions for a given period of time [45]. With respect to human operators failure is considered as complete or partial loss of work capability as the result of which the operator can no longer meet one of the given efficiency criteria [154].

Technical methods of evaluating the reliability of control systems presuppose a determination of the quantitative indicators of static reliability (the ability of the system to maintain adequacy to assigned goals for a given time) and dynamic reliability (ability to maintain quality of functioning above an assigned level) [48].

The apparatus of reliability theory is well-developed applicable to determining static reliability. Attempts to use it to evaluate operator reliability have demonstrated that it has limited potential in relation to diagnosing stable failures because it does not take account of the specifics of the person's work capability. Therefore, a number of authors have proposed their own techniques for determining the reliability of ergatic systems taking operator error into account. In particular, A. Sueyn [160] introduced the method of forecasting system reliability by evaluating the probability of an error during performance of elementary operations in the algorithm of operator activity.

R. Kaufman [160] showed that simple empirical formulas may be used for practical calculations of reliability. In this case the number of operator errors is defined as a function of the product of the cost of equipment, its weight, and its volume. Other methods of calculating operator reliability are given in work [160].

The most highly developed calculation method of determining operator reliability today is the structural method [157], which is based on the following principles:

- evaluation of system reliability based on analysis of the structure of operator activity;

- a hierarchical structure of levels of description of the activity.

Assuming that operator activity can be represented in the form of distinct elementary operations, the author proposed evaluating the results of activity by no-failure operation and speed of performance of each structural function. In this case the reliability indicators can be determined on the basis of experimental findings or data in the literature. The author believes that operator reliability when performing the particular actions that make up the algorithm of activity comprises program, parametric, and time reliability. Program reliability is determined by the probability of error-free or erroneous performance of particular operations, while parametric reliability is an indicator of the probability of precise or imprecise performance of operations and time reliability means the probability that the operation will be done on time.

The method presented in [62] is based on searching for a certain functional of the indicator of the goal of control. Operator reliability during control of an actual system is determined on the basis of modeling the environment that influences the system. It is proposed that the probability of system failure owing to operator failure be determined by modifying its impact within the working range of the system and assigning weighted coefficients.

Types of Failures Permitted by the Operator

A. I. Gubinskiy and G. V. Sukhodol'skiy [67] have proposed a classification of failures taking account of human psychophysiological characteristics. They consider a failure to be an action performed by the operator either mistakenly or at the wrong time. Work [68] gives an example of designing a "system to monitor the human being."

All mistakes made by the human being can be arbitrarily broken into three groups:

1. mistakes in time of performance of action;

2. mistakes in the actions themselves;

3. gross blunders.

Gross blunders involve substituting one action for another. According to the findings in work [131] this most often occurs as the result of operator fatigue, poor health, or lack of training. But gross blunders may also be made by experienced operators when the activity is well-organized. In work [24] operator failures are classified into predictable and random. The predictable failures include errors which may be identified by the research process and eliminated when creating optimal conditions for the activity, while random failures involve errors caused by the stochastic nature of human behavior. Moreover, the latter type of errors cannot, in the author's opinion, be identified or studied because its nature is unknown.

When performing a series of arithmetic operations the true answer, according to the findings of work [212], can only be obtained after numerous repetitions of the process of computation, which is improbable for actual conditions. Therefore, it is proposed that a modal value of the answer be used as the correct result of calculations. According to the findings of this author, the distribution of precision of responses can be represented in the form of two parts: a truncated symmetrical part that is close to normal, and the remainders on the left and right resulting from gross blunders (misreading, carrying mistakes, and the like). The estimated probability of these responses is 0.2. The answers, whose deviations are not more than 1.5 times from the modal, make up a symmetrical distribution. Despite the random character of the results, the probability of receiving the correct answer grows with an increase in the professional training of the person doing the calculation.

Works [66-68] distinguish types of failures by how they are eliminated:

— temporary, unstable failure — a failure whose cause is self-eliminating;

- operational failure caused by failure to achieve the goal owing to shortage of time;

- temporary, stable failure, which is eliminated by creating special conditions;

- terminal failure, which cannot be eliminated or is eliminated only after replacement of the system.

A special feature of the functioning of an ergatic system is that its reliability depends on the amount of time allowed for the operator to carry out the algorithm. In this case, even though the tecnical equipment and operator are in working condition, failures related to inadequate time to perform the series of operations within the algorithm occur [191].

A decline in operator reliability in the time area may occur not only as the result of a time shortage, but also because the operator's operational memory is overloaded. This type of mistake is quite thoroughly analyzed in work [196a]. The author there believes that it is most convenient to analyze the probability of errors related to information overload as the result of time shortage or overloading the operator's operational memory by the methods of mass service theory.

Numerous authors [17, 63] distinguish errors made by an operator into those resulting from inadequate qualifications and those determined by the characteristics of the individual person.

The information given above is far from complete. Rather it illustrates the multiplicity of problems that arise in studying the rules and patterns of human labor activity, which are thoroughly illuminated by advances made in this field. Nonetheless, on the level of meeting the challenges of diagnosing and forecasting human work capability in control systems we may consider the following fact to be established: there is a definite relationship between the results of operator activity and the dynamics of the psychophysiological indicators of the operator's state, and this relationship is in some way linked to internal (individual characteristics, the person's previous history) and external (content of the activity) factors.

The methods used today to identify this relationship were developed for solving similar problems in relation to technical devices. Adaptation of these techniques to the new problems requires a more flexible consideration of the nature of work capability in the object under study, in particular, the special features of purposeful human behavior.

We know that in the process of activity to achieve an assigned result the operator chooses the necessary sequence of actions with due regard for the technical capabilities of the system, the magnitude of existing disturbances, analysis of analogous situations in the past, and so on. Investigators believe that in this case a certain "functional system" oriented to achieving the concrete result is formed within the operator's organism. The material foundation of the "functional system" and the carrier of the essential sequence of control operations will be the psychophysiological systems of the organism, between which linkages are established for the period of working toward the result. In other words, the formation of the "functional system" is accompanied by a change in intersystem interaction within the organism, which must inevitably be reflected in the dynamics of the psychophysiological indicators of the operator's state that are recorded.

In addition, the physiological systems (carriers of the program of action selected by the operator) perform functions related to the vital activity of the organism. Therefore, the "functional system" formed on their basis performs at least two tasks: support for the functioning of the operator as an element of the control system, and support for the functioning of the operator's organism as a biological object. It is difficult to differentiate the features of the impact of the information flows related to these tasks on the character of intersystem interaction within the organism because signals on the "internal sphere" of the organism cannot be observed. This may mean that even in similar situations (from the standpoint of conditions of activity), the character of the relationship between the results of activity and the parameters of psychophysiological indicators will be unique, that is, corresponding only to the given interval of observations. This is probably why existing models of operator activity have limited spheres of application.

Because these features of describing operator activity apply to the analysis of purposeful behavior by biosystems in general, they can be summarized in the form of a principle of adequacy of description of behavior, which we will state as follows.

When describing purposeful behavior by biosystems, the form of the relationship between indicators of the process of pursuing the goal, the characteristics of signals on the process, and change in indicators of the functioning of information processing and vital systems is preserved only while there exists a concrete "functional system" formed to achieve this goal.

Chapter 4. State of the Organism and Operator Activity in a Stress Situation

1. Changes in the Organism During Stress

The contemporary phase of development of human society has an exceptionally intensive rhythm of life. This rhythm is dictated by the conditions of highly intensified production processes and the need to process an enormous amount of every possible kind of information daily and to participate actively in different areas of human activities. This situation is an organic consequence of contemporary social transformations and scientific-technical progress which (considering the significance, speed, and extent of the transformations) may be called a second scientific-technical revolution.

In the given stage of technical development the principal structural unit of production is the automated "man-automaton" complex. Therefore, the problem of human beings in automated control systems has become a pressing one, in particular preserving the efficiency of activity of the human operator and the operator's functional state within optimal ranges. The state of operators and their work capability must be monitored constantly to prevent emergency situations. Many investigators [1, 2, and others] have demonstrated that operator activity has a nonmonotonic dependence on the degree of the physical and mental loads that accompany the particular production process. The efficiency of activity increases with growth in the intensity of the labor process; it is as if the operator's potential were stimulated. However, this relationship lasts only to a certain point. Further growth in the intensity of the production process leads to a decline in the quality of work all the way to a complete refusal to work. The capability for steadily maintaining optimal working parameters (work capability, "vigilance," noise resistance, and so on) during assigned time intervals and with every possible complication of the situation determines the operational reliability of the worker [3].

There are many different ways to improve the efficiency of operator work and reduce the number of emergency situations caused by the human factor in automated systems. Among these ways are vocational selection, training, and turning operator functions over to automatic machinery. But it seems to us that these methods will not be adequately founded until we have learned to reliably analyze the state of maximum exertion of the operator's mental and physical strength, which precedes an emergency situation. It is also important to define this state because prolonged tension may have a bad effect on the person's health.

Cardiovascular problems, in particular hypertonia, ulcers, neuroses, and psychoses, may result from excessive nervous tension.

The problem of stress, of mental tension , is a multifaceted one. It can be viewed from a general biological standpoint as a system of adaptive acts that was developed and refined in the process of evolution. In its physiological aspect stress involves mechanisms to regulate the activity of various functional systems of the organism. The psychological consideration of stress looks at its influence on various aspects of mental activity: perception, memory, attention, mental operations, links to personality traits, character, and experience, adaptation to different types of stress, questions of preventive psychological training, and the role of the psyche in post-stress recovery [4]. The social aspect of stress involves behavior in a collective, biological compatibility in stress situations, and the influence of the collective atmosphere on change in the functional state of a person. If stress as considered from a medical point of view the main interest is disruptions of the normal activity of various functional systems, organs, and the psyche as the result of long-operating or especially harmful stress stimuli and working out recommendations for treatment based on subtle knowledge of the mechanism of stress-related changes in the organism. We will consider the problem of stress in greater detail in the physiological aspect.

Stress may be referred to as a multifaceted problem in another respect as well, which is to speak of the integrated (overall) activity of the organism, including biochemical changes and changes in physiological indicators, behavior, and mental functions. When studying this problem one must not overlook any of these facets. This is especially important because many schools of physiologists assign the principal role in the course of a state of stress to biochemical changes, considering them the primary correlates of the state. But experience demonstrates that biochemical changes during stress are well expressed in acute periods but poorly expressed during prolonged chronic strain. Where there is mild strain practically no changes at all will be detected because the mechanisms of homeostatic regulation nullify the changes almost immediately. In addition, there are individual differences which produce a great spread in the quality and magnitude of biochemical changes. In view of these factors, biochemical changes cannot be considered preeminent among the correlating changes.

Based on material that has now been accumulated, we may say that biochemical changes are the background against which different mental and physiological changes occur. But no one physiological parameter, nor biochemical change, can be a reliable indicator of the state of tension. This is graphically illustrated by cases described in the literature where arterial pressure is invariant in stress situations because the increase in the systolic volume of the heart is compensated for by a decline in pressure in the peripheral vessels. Somatic changes are more or less subject to arbitrary regulation. The mental categories, unfortunately, are difficult to subject to direct objective monitoring, while the indirect techniques used in these cases introduce an element of subjectivity and do not take account of the possibility of random influences. The forms of behavior that reflect internal changes in the organism are also to some degree subject to random regulation. Thus, we may acknowledge that we do not have an adequately reliable correlate for tension. The only way to make diagnosis of the state of tension better is to increase the number of indicators of this state.

The term "stress"(in Russian "napryazheniye") is borrowed from physics (derivative of force and resistance) and in translation to biological language signifies the impairment and defensive reactions of the organism (the action which leads to the changes is called stress). The biological concept of stress was formulated some 40 years ago by the Canadian scientist Selye, who said that stress is "excessive strain," "a state that occurs under the influence of some particular stressor and is found in the form of a specific syndrome which includes all the changes nonspecifically reproduced in the biological system" [5]. He called the full set of reactions in a state of stress the adaptation syndrome, because it is the basis of adaptive behavior.

Therefore, stress is a set of adaptive and defensive reactions by the organism to all influences which have a tendency to disturb the dynamic equilibrium of various processes in the organism. As we will see later, the set of adaptive and defensive reactions is a neuroendocrine cycle of great complexity which causes changes in literally all manifestations of vital activity of the organism.

A number of works use the term "stress" not to mean general stress, but rather its highest point, when organic changes take place in the organism. Pre-stress states are viewed as various types of emotional states [6]. But this division does not cover a whole number of states which are unquestionably states of heightened tension and have virtually no emotional coloring (for example, solving "indifferent" problems that require great self-control and intensity of thought).

After analyzing information available in the specialized literature, we made an attempt to classify the different states of extreme stress and the methodological procedures necessary to create it (see Table 1, next page).

Systematic study of the state of stress began in the 19th Century. The famous French physiologist Bernard (1813-1878) stated the proposition that the fundamental feature of all living beings is their ability to maintain constant internal environment despite changes in the external environment. Any change in the environment that matters to the organism elicits defensive reactions by the organism to restore the disturbed balance. This occurs through special regulatory mechanisms that monitor the constancy of different parameters of the internal environment [7].

The American physiologist W. B. Cannon (1871-1945) introduced a special term, homeostasis, for the ability of the organism to maintain a constant internal environment [8]. Any influences leading to disturbance of homeostasis lead, the scientists believe, to vegetative and hormonal changes that can be viewed as a manifestation of the organism's mobilization of energy to avert the danger: readiness for resistance or flight.

Such changes in parameters of the internal environment from their initial level are reversible if they lie within the range of capabilities of the homeostatic

Table 1.

Stressors Classification	Emotional Coloring: Imaginary	Real	Positive	Negative	Methodological Procedures
		EMOTIONAL			
		Physical			
Stressors that cause unpleasant or painful sensations	-	+	-	+	Physical injury, irritants that exceed the background, discomfort, hypokinesia, and so on
Stressors of unexpectedness	-	+	-	+	New unexpected stimulus
		Mental			
Stressors of failure	+	-	-	+	Recalling past failures, imagining failure
Stressors that cause a feeling of fear	+	+	-	+	Emergency, darkness, expectation of criticism or evaluation, threat of punishment, and the like
Emotionally colored materials	+	+	+	+	Showing a film or picture, the presence of an enemy or friend, playing out various situations in the mind
Pharmacological substances that cause emotional states	-	+	+	+	Piperoxane, adrenalin, and so on
		OPERATIONAL			
Stressors of pace and speed	-	+	-	-	Time shortage, information overload
Complexity of problem-solving	+	+	-	-	Conflict situations, merging of two similar mental processes (black-red tables), a difficult mental problem, and insolubility

mechanisms and irreversible if the magnitudes of the deviations are significantly greater than the range within which the homeostatic mechanisms can function normally. In the latter case the organism dies.

Russian and Soviet scientists made major contributions to formulation of the theory of stress long before Selye. I. P. Pavlov wrote many times that harmful influences on the organism elicit local reactions and reflex-nerve-humeral changes which are a "physiological measure" of the organism's defense. L. A. Orbeli [9] and his students made detailed investigations of the adaptational role of the coordinated activity of the cerebral cortex, sympathetic nervous system, pituitary body, and adrenal glands.

At the present time the concept of stress is an established concept and it is most commonly defined as the attempt to restore the disrupted homeostasis of mental, physiological, and biochemical processes in the organism. Stresses are caused by any conditions that disrupt homeostasis [10, 11].

What are the regulatory mechanisms that guard the well-being of the organism? All attempts to explain the adaptive reactions of the living organism can be schematically classified as follows [12]:

1. the hume. ' theory of medicine, which goes back thousands o. ..rs;

2. the theory .. neurism, which has developed in the last 150 years;

3. the "cellular" theory of Virkhov;

4. the neohumeral theory, whose founder can be considered

At the present time the neurism theory and Selye's neohumeral theory are generally accepted, and we will deal with them in greater detail. Selye's theory considers the endocrine-biochemical aspect of stress in detail [13-16].

Any adequately strong and unusual influence of exogenic or endogenic origin (sound or light, infectious disease, and so on) on the organism, except for an effect specific to the given agent (for example, vibration of the tympanic membrane to sound) evokes a whole complex of nonspecific reactions. These reactions aim at better adaptation of the organism to the unexpectedly changed living conditions and, as already mentioned, were called the adaptive syndrome by Selier, while the state of mobilization of defensive forces itself was called stress.

Selier distinguishes between the generalized adaptational syndrome (GAS) and the local adaptational syndrome (LAS) or adaptive reactions in the limited part of the body which is directly affected by the stimulation. The generalized syndrome is a response reaction by the entire organism which goes through three successive stages when the action of the stressor is sufficiently long (see Figure 7 below).

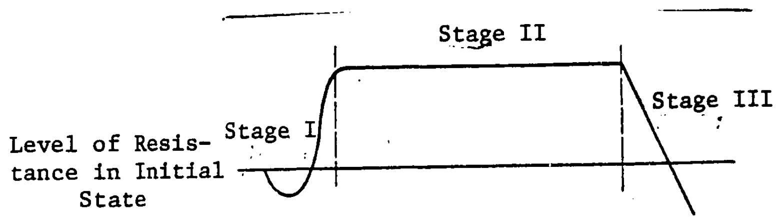


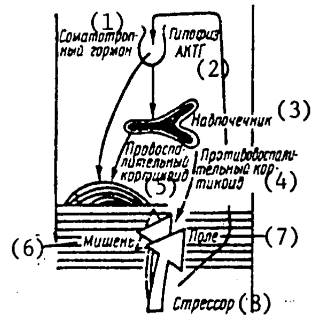
Figure 7. Stages of the Generalized Adaptation Syndrome

During the first stage — alarm — the initial level of organism stability and resistance at first declines slightly (shock), and then returns to the norm (countershock). Selye called this stage the "call to arms of the organism's defensive forces." If a very strong or harmful agent acts on the organism, it may perish during the alarm period. But if the effect is moderate, the alarm stage is followed by adaptation to the influence, the stage of resistance. The level of organism stability in this stage exceeds the initial level [14, 15]. Reactions in the alarm and resistance stages are opposite. When the harmful agent is active for an extended period, the resistance stage may be followed by the third stage, exhaustion and death of the organism. The symptoms of the third stage recall the symptoms of the first stage, but now they are irreversible.

But what happens in the organism during stress and allows its resistance to vary within quite broad limits? During the first stage (shock or alarm) a number of phenomena are observed in the organism: hemoconcentration, hypochloremia, hypercalcemia, generalized tissue damage with predominantly dissimilation phenomena (catabolism), hypothermia, lowering of blood pressure, vascular and muscular hypotonia, leukopenia, eosinopenia, and heightened permeability of the serous membranes of the capillaries. In the second stage there are changes in the opposite direction, specifically thinning of the blood, hyperchloremia, anabolism of tissues with return to normal weight, alkalosis, and so on. The reactions of the exhaustion phase resemble the alarm phase.

During the development of stress a number of morphological changes are also observed. The most expressed changes are involution of the thymico-lymphatic apparatus and enlargement of the adrenal cortex with signs of intensification of secretion. It has now been established [17, 18, 19] that changes are observed during stress in other organs and tissues as well: pituitary body, epiphysis, thyroid gland, parathyroid gland, pancreas, sex organs, liver, myocardium, kidneys, membrane of the stomach and intestines, and cells of the brain. In each of these organs histologists find two groups of phenomena: damage and defense [18]. In the first stage two groups of reactions are observed, while in the second defensive phenomena predominate and in the third damage phenomena are dominant. In a number of his works Selye tries to represent the intimate mechanism of changes that lie at the foundation of the generalized adaptation syndrome on the basis of vast experimental material (see Figure 8 below).

Figure 8. Mechanism of Changes Taking Place in the Organism During Stress



Key:
(1) Somatotrophic Hormone;
(2) Pituitary Body, adreno-corticotrophic hormone;
(3) Adrenal Gland;
(4) Anti-Inflammatory Corticoid;
(5) Inflammatory Corticoid;
(6) Target;
(7) Field;
(8) Stressor.

In some way (which Selye does not explain) the stressor causes stimulation of the hypothalamus, which produces a certain adrenocorticotrophic liberating factor. This stimulates the pituitary body and causes it (the front part) to secrete adrenalcorticotrophic hormones, which stimulate the secretion of hormones of the adrenal cortex. The adrenal cortex hormones are divided into two groups: the anti-inflammatory hormones or glucocorticoids (of the cortisone type) and the inflammatory hormones or mineral corticoids (such as desoxycorticosterone and aldosterone).

The anti-inflammatory hormones affect carbohydrate metabolism (which is the source of their second name, glucocorticoids), enhancing glycogenesis through proteins, which increases the sugar in the blood and intensifies the precipitation of glycogen in the liver. They intensify the breakdown of proteins, which promotes catabolic processes and is detected by an increase of nitrogen in the urine. They retard the development of the basic substance of connective tissue by reducing the number of mast cells that produce hyaluronic acid, which lowers the inflammation potential of the organism, thus increasing organism sensitivity to infection, retarding the processes of healing of wounds, and diminishing allergic reactions. They repress lymphatic tissue and cause involution of the thymus, which is accompanied by a decrease in the quantity of lymphocytes and eosinophils. The inflammatory hormones are to some degree the antagonists of the glucocorticoids. They promote an increase in inflammatory potential of the organism (resistance to infections and rapid healing of wounds), increase protein synthesis, and have little effect on carbohydrate metabolism but a significant effect on water-salt metabolism (therefore they are also caused mineral corticoids) by retaining sodium in the organism and removing potassium. During stress more anti-inflammatory hormones than inflammatory hormones are usually secreted. It is in precisely this element of the organism's response reactions to the effect of a stressor that the meaning of the term "stress" as an integrated response by the organism, including elements of damage and defense, is very graphically demonstrated.

It should be noted that the front portion of the pituitary body affected by stimuli from the hypothalamus secretes not only adrenocorticotrophic hormones, but also somatotrophic hormones, which affect overall growth of the organism and cause enlargement of the thymus, lymph nodes, spleen, and liver and hypertrophy of the adrenal cortex, while increasing sensitivity to corticoids. This hormone is similar to the mineral corticoid in its effect on the internal sphere. The hormones of the front part of the pituitary body and adrenal cortex are customarily called the adaptive hormones.

In addition to the general reaction of the organism which follows the "law" of the GAS, a local inflammatory reaction, the local adaptation syndrome (LAS), appears at the point of the damage. This reaction has the same stages as the GAS: shock during which a certain necrosis of cells and connective tissue fibers and an acute inflammatory process are observed; resistance during which different types of cells form (defensive granulation barrier). If the influence is especially harmful and long-lasting, the third stage ensues: necrotic disintegration of tissues. The LAS and GAS not only share common features in their courses, but are closely interrelated [15]. Any agent which causes a local inflammatory process also produces a general effect because pulses from the damaged area reach the hypothalamus and set the mechanism of the GAS in action. Then the corticoids, having been secreted in a certain stage of the organism's general reaction, affect all tissues of the organism and thus influence the local center of damage.

In a number of works Selye acknowledges that not everything occurring in the organism fits perfectly within the proposed scheme. For example, it cannot be said that the adrenal cortex-pituitary body system is the only system responsible for the full range of GAS reactions. It is the main one, yes, but not the only one. The reactions observed with the GAS can occur partially when stressors act on animals whose pituitary bodies and adrenal glands have been removed. It is thought that the reactions observed in this case are the result of the action of hormones from the thyroid gland [14, 20, 21]. The liver probably also plays a significant part in adaptation processes, and it is where steroid hormones are broken down [21]. Works have been written on the role of the pancreas in the GAS [20].

The conception presented by is interesting for its abundance of experimental material. It has received wide distribution in domestic literature [4, 10, 11, 13, 19, 21-26, and others]. But Soviet specialists take a critical approach to Selye's conception, correctly noting that it has a number of shortcomings. Above all this refers to the one-sidedness of the conception: attention is directed exclusively to humeral-endocrine reactions. The role of the central nervous system and cerebral cortex in regulating the activity of the internal secretion glands is overlooked. The author makes only incidental mention in some works of the fact that he is not denying the significance of the nervous system in shaping the GAS. It is possible that an unclear understanding of the leading position of the central nervous system and the organism's systemic reactions to maintain its optimal state was the basis for Selye's idealistic philosophical views. Attempting to construct a general theory of medicine, he declares himself an advocate of the teleological principle in biology and medicine [11, 27]. Thus, Selye's conception represents only a partial manifestation of total vital activity, one link (the humeral) of the long and complex chain of processes which unfold in the organism in response to an extraordinary stimulus.

Leading scientists of the past and our contemporaries today, especially Soviet physiologists, have developed the materialistic direction defined by I. P. Pavlov as "nervism," which recognizes the decisive importance of the higher sections of the central nervous system for all vital manifestations of the organism, and particularly for adaptive behavior. The foundation of "nervism" as a scientific school was laid by S. P. Botkin and I. M. Sechenov, who proved that the nervous system influenced the very diverse processes in the organism.

The works of V. M. Bekhterev convincingly demonstrated the dependence of the activity of internal organs and internal secretion glands on influences from the cerebral cortex. The conditioned reflex method of I. P. Pavlov and his school made it possible to use the internal organs and different systems of the organism as indicators of the state of the higher parts of the brain. The work of the A. D. Speranskiy school [28] demonstrated the importance of the central nervous system for restoring the normal state of the organism disrupted by disease-creating factors.

The works of K. M. Bykov and his associates were a major contribution to the theory of nervism. They established the direct role of the cerebral cortex in the activity of internal organs (the cortico-visceral theory of the pathogenesis of certain illnesses). The works of L. A. Orbeli [9] and his students, devoted to studying the morphological and functional links of the cerebral cortex with the autonomous nervous system, which integrates the activity of the internal organs and internal secretion glands, are very interesting in this respect. They showed that the sympathetic and parasympathetic systems are represented in the cortex of the large hemispheres. They establish the leading role of the cortex and the mutual influence of the higher segments of the central and autonomous nervous system, gave a detailed description of the adaptational role of the coordinated activity of the sympathetic nervous system, pituitary body, and adrenal glands, and investigate also the trophic function of the sympathetic nervous system (adaptation processes in the tissues of the organism).

Many works have now appeared devoted to regulation of the activity of the internal secretion glands by the central nervous system and regulation of the adaptation syndrome by the cortex of large hemispheres of the brain [6, 25, 27, 29-35].

We should note the entire school in physiology which considers an increase in organism resistance resulting from the action of any stressor (the second stage of resistance according to Selier) to be the result of an inhibitory influence from the central nervous system on the response reactions of the organism, which is subjected to unfavorable influences: the Pavlov theory of defensive inhibition, and dominant inhibition [23]. Many examples can be given from everyday life where the quality and intensity of reactions and behavior in a stress situation depend on the evaluation of this situation and the social motives of the individual, which again indicates the coordinating role of the central nervous system in the state of stress. More evidence of this is found in studies where hormonal changes characteristic of a state of stress were evoked by conditioned reflex [36, 37].

In order to represent the organism of the complex set of organism reactions in a state of stress, let us look first at its morphological substrate. Analyzing the factual material presented in works [6, 38-40, and others], we will draw a flow-chart of formations and nerve linkages that participate in the realization of this state (see Figure 9 below). The pulse from the receptor which is affected by an

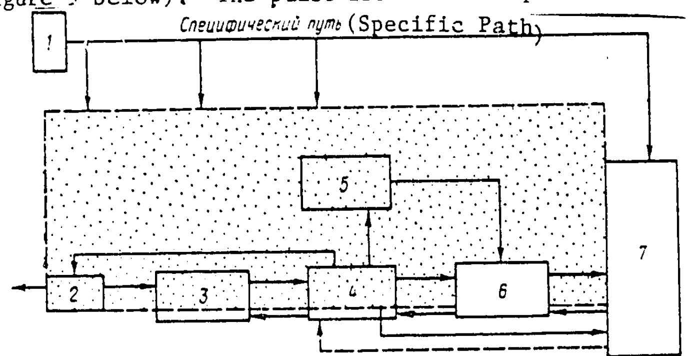


Figure 9. Flowchart of Formations and Nerve Connections Participating in Realization of the Adaptation Syndrome

Key: (1) Receptors;
(2) Reticular Formation of the Medulla Oblangata and Spinal Cord;
(3) Limbic System of the Middle Brain;
(4) Hypothalamus;
(5) Nonspecific Nuclei of the Thalamus;
(6) Limbic System of the Forebrain;
(7) Neocortex.
[The dotted space represents the reticular formation of the stem of the brain.]

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adequate stimulus travels along two paths: specific (to the projected zone of the cortex of the large hemisphere) and nonspecific (to the reticular formation of the brain). Branching out from the specific path into the reticular formation may be accomplished at different levels of the central nervous system. For the stress state mechanism to be triggered, the pulse must reach the hypothalamus-limbic system [7], or as it is usually put, the limbic system. This system includes formations of different levels of the central nervous system: formations of the middle brain (central brain matter, operculum) and nonspecific nuclei of the thalamus (anterior nuclei, nuclei of the middle line, and reticular nucleus). In the forebrain the limbic system includes the areas of the archicortex and old cortex (nippocampal and singular convolutions, the hippocampus, and the olfactory bulb) as well as numerous subcortical formations (the nuclei of the amygdaloid complex and septum). The center of the limbic system, the hypothalamus, is a kind of nodal point that connects the above-mentioned formations. The existence of strong morphological ties between the hypothalamus, the nonspecific nuclei of the thalamus, the singular convolutions, and the hippocampus enables us to hypothesize the existence of a cyclical system in which stimulation can circulate between the hypothalamus and the limbic system of the forebrain (see Figure 10 below). It is possible that this system is the neurophysiological foundation of emotional manifestations.

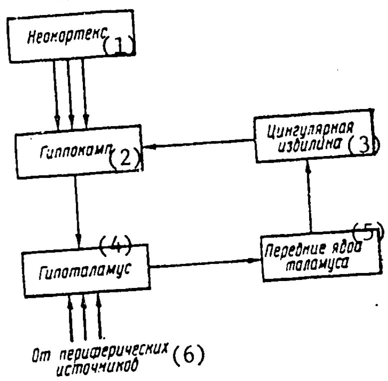

Figure 10. Linkages Between the Hypothalamus and the Limbic System.

Key: (1) Neocortex;
(2) Hippocampus;
(3) Singular Convolution;
(4) Hypothalamus;
(5) Front Nuclei of Thalamus;
(6) From Peripheral Sources.

From the limbic system pulses go to the neocortex. In this connection we should note the role of the limbic system of the forebrain as a transmitting link between the neocortex and the hypothalamus, because practically no efferent fibers go directly from the new cortex to the hypothalamus. The return linkage of the hypothalamus and limbic area of the middle brain with the reticular formation of the stem of the brain plays an important role. Efferent pulses from these formations give rise to descending (toward the spinal cord) and ascending (toward the neocortex) streams of pulses.

The functional interrelationships among these structures of the complex are accommplished as follows. The immediate generator of all functional and biochemical changes is the hypothalamus, which represents the highest center of the autonomous nervous system and is closely linked to the activity of the pituitary body. The lower-lying structures (reticular formation) are the energy base, so to speak, of this formation. The mutual influences of the hypothalamus with the above-lying formations — the limbic structures of the forebrain and the cortex of the large hemispheres, are more complex and differentiated. If the hypothalamus is stimulated directly or by reflex (stimulation of receptors), diffuse stimulation of the cortex is recorded parallel with stimulation of the hypothalamus. If the hypothalamus is incapable of perceiving these stimulations, no activation is observed in the cortex, which gives reason to hypothesize direct participation by the hypothalamus in diffuse stimulation of the cortex. The cortex of the large hemispheres has a dual influence on the hypothalamus [6]. The frontal areas retard its activity (early stages of narcosis, removal of the forebrain, and cutting its efferent paths are associated with an increase in vegetative activity), while the sensory projection areas, by contrast, stimulate it (placing filter paper soaked in strychnine against the projection zone causes "strychnine" discharges not only in the cortex, but also in the hypothalamus).

The mutual influences between the hypothalamus and different limbic structures of the forebrain are also ambiguous, complex, and not fully clarified. Some authors

[23] single out an inhibitory system (hippocampus, singular area, and septum of the brain) and a stimulation system (amygdaloid nuclei, and posterior orbital surface) which have corresponding effects on the activity of the hypothalamus. We should emphasize specially the importance of the functional link between the hypothalamus and the hippocampus for diurnal periodicity and secretion of adreno-corticotrophic hormone.

The existence of the above-described morphological and functional links among different structures of the central nervous system and clinical and experimental observations give reason to think that the mechanism of all the changes taking place during the state of stress is determined by the coordinate activity of the hypothalamus-limbic system, reticular formation, and neocortex. All changes during stress may be divided into three types of reactions: changes of the internal sphere (metabolism, and the functions of organs and systems), external reactions which are the result of internal changes (expression of the corresponding emotions), and external reactions aimed at active intervention in the surrounding situation after comprehension of what is happening (flight, attack, and defense). The first two types of reactions are accomplished by the coordinated activity of the reticular formation of the stem of the brain, the limbic area of the middle brain, the hypothalamus, and the limbic system of the forebrain. This complex is the "general staff" of the visceral activity of the organism.

Perception, comparison with past experience, comprehension, choice of tactics, and deliberate regulation take place at the highest level, in the neocortex. It has been proven experimentally that stimulation of the sympathetic part of the autonomous nervous system or injecting adrenalin into the blood, which is the basis of humeral changes in full-fledged stress, leads only to diffuse stimulation. The same biochemical changes, but aroused by a certain situation, are accompanied by an integrated act of purposeful behavior. The coloring of the behavior in this case may differ and depends on the organism's interpretation of the situation. If the threatened factor can be eliminated, the response reaction is rage; if not, fear arises [36].

Thus, stress is a systemic reaction of the organism which may be elicited without the participation of the cortex of the large hemispheres of the brain also, but in this case fundamental changes in the state of the organism will be observed on the order of general stimulation without involving the individual's feelings. The interpretation of this general stimulation of the organism and an active and conscious attitude toward the situation are possible only with active participation by the cerebral cortex [4]. Defense reactions, if we exclude influence from the cortex, are unconditioned reflexes. But if the connection with the cortex has not been broken, the adaptation-defensive complex follows the type of the conditioned reflex.

This kind of "division of duties" follows from the general evolutionary purpose of the cortex of the large hemispheres as an organ which critically evaluates a changed situation and works out further tactics of behavior based on life experience. But what happens when the integrative system of the stress state described above is activated? The main result of its activity is activation of the autonomous nervous system and pituitary body, whose highest regulating center is the hypothalamus.

Activation of the higher autonomous centers located in the hypothalamus (the centers of the sympathetic part of the autonomous nervous system are in the posterior hypothalamus and the centers of the parasympathetic parts are in the anterior) leads to a change in the activity of the internal organs. The sympathetic effect is characterized by an increase in the frequency of heart contractions, a rise in arterial pressure, dilation of the pupils, a narrowing of the blood vessels (paleness), a weakening of peristalsis and the activity of the glands of the gastrointestinal tract, an increase in perspiration, a reduction in the spleen (as a result of which the number of erythrocytes in the blood increases), a lessening of salivation (dryness in the mouth), and so on. Special note should be taken of the hyperfunction of the brain matter of the adrenal glands resulting from the arrival of the stimulation along the sympathetic nerve. The adrenalin secreted by the brain matter causes an immediate increase in sugar content in the blood by breaking down the glycogen of the liver. This measure to increase the resources of muscular energy was essential on the evolutionary level for adequate organism reaction in changed conditions (flight and attack).

In most cases of the stress state the sympathetic effect is dominant, in some situations the influence of the parasympathetic nervous system can be detected (urination, defecation, dilation of blood vessels, reddening of the skin and drop in arterial pressure, lowering of body temperature, tears, and so on).

Just like the sympathetic system, the parasympathetic system has a powerful hormonal action on the biochemical balance of the internal environment of the organism in addition to reactions of nerve origin. The arrival of parsympathetic pulses in the pancreas stimulates the pancreas to secrete additional amounts of insulin, which reduce blood sugar content.

It is obvious that any stress situation is the algebraic sum of the sympathetic and parasympathetic effects. As a rule one of these effects is stronger, and it is what is manifested, despite the existence of opposite reactions which, owing to their small scope, are not recorded. Since the time of Shirrington, the method used to isolate one of the effects in pure form has been to sever or destroy the competing section. The participation of one of the systems can also be established by determining the amount of adrenalin (hormone from the cortical part of the adrenal glands) and insulin (hormone from the pancreas). Figure 11 below shows P. V. Simonov's diagram [41] of the participation of these parts of the autonomous nervous system in different situations.

Gel'gorn [6] uses this breakdown: sympathetic reactions prevail for unpleasant passive emotions (fear), while pleasant emotions are accompanied by parasympathetic effects; but, unpleasant active emotions (indignation, rage, and fury) are associated with both sympathetic and parasympathetic effects (for example, a rise in blood pressure, frequency of heart contractions, and blood sugar and intensification of the activity of the gastrointestinal tract).

We do not think, however, that the proposed scheme can be literally applied to all situations in life. Existing individual differences may cause significant changes.

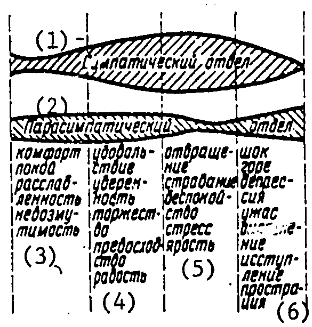

Figure 11. The Participation of the Sympathetic and Parasympathetic Parts of the Autonomous Nervous System in the "Design" of Various States.

Key: (1) Sympathetic Part;
(2) Parasympathetic Part;
(3) Comfort, Tranquility, Relaxation, Imperturbability;
(4) Satisfaction; Confidence, Triumph, Superiority, Joy;
(5) Revulsion, Suffering, Worry, Stress, Rage;
(6) Shock, Grief, Depression, Terror, Torpor, Frenzy, Prostration.

In addition to the vegetative (autonomous) changes we have considered which are caused by increased activity of the sympathetic and parasympathetic parts of the nervous system and find expression in the action of nerve stimuli and hormonal changes (adrenalin and insulin), there is change in the activity of the pituitary body. It is so closely linked to the activity of the hypothalamus that they are often considered a single complex. Stimulation travels from the hypothalamus to the pituitary body by a neurohumeral route. The neurosecretion produced by the nerve cells of the hypothalamus reaches the pituitary body, first of all, through the blood vessels that run from the hypothalamus to the pituitary body through its peduncle, and in the second place, along the long axons of the nerve cells of the hypothalamus, which also reach the pituitary body through its peduncle. It should be noted that the axons go mainly to the posterior part of the pituitary body, being nerve tissue, while the chemically active matter in the blood vessels is transferred to the anterior part of the pituitary body, represented by glandular cells. Thus, any region of the hypothalamus where neural secretion is produced can exercise an influence on the anterior part of the pituitary body, but the posterior part of the pituitary body reacts chiefly to change in the activity of formations of the anterior hypothalamus, which has long axons running to it from its cells. But this is not the only difference between the anterior and posterior parts of the pituitary body. The anterior part of the pituitary body has a more important role in constructing the state of stress. It produces the "trophic" hormones, in particular adrenocorticotrophic hormone, thyrotrophic hormone, and hormones that stimulate activity in the sex glands.

The posterior part of the pituitary body, which is not a gland, produces antidiuretic hormone and a few other hormones (oxycitin and others) which do not disrupt biochemical balance as significantly as the hormones of the anterior part do. Antidiuretic hormone maintains the normal osmotic pressure in the liquid environments of the organism by regulating the absorption of water in the tubules of the kidneys and also stimulates the secretion of adrenocorticotrophic hormone by the anterior part of the pituitary body. The secretion of "trophic" hormones by the anterior pituitary body causes a whole cycle of biochemical changes which were described in detail during our consideration of Selier's ideas.

We must also consider somatic effects to get a fuller idea of the components of the state of stress. It is common knowledge that the state of stress, and especially that area of these states that carries an emotional coloring, is accompanied by activity of the skeletal musculature (posture and mimic reactions). These reactions are caused by descending influences of the hypothalamus through extrapyramidal routes (contractions of the somatic muscles may be evoked by stimulation of the hypothalamus after preliminary removal of the hemispheres of the brain) or influences from the motor part of the cortex which arise owing to hypothalamus-cortical activation. It should be noted that an increase in the tone of the skeletal musculature reflects an increase in the activity of the sympathetic part of the hypothalamus. Thus, stimulation of the posterior hypothalamus is accompanied by turbulent emotional manifestations and an increase in the tone of the skeletal musculature, whereas stimulation of the posterior hypothalamus (higher centers of the parasympathetic part of the nervous system) is associated with relaxation, decrease in activity, and sleep. The entire complex of reactions is depicted schematically in Figure 12 below.

As specialists working in the field of neurobionics, we are especially interested in attempts to formulate a theory of stress in the organism as a closed system. In such a system (by analogy with general physics) stress is regulated by special mechanisms [42]. These mechanisms are based on direct links and feedback [43]. Positive feedbacks support processes at the highest level of intensity, while negative feedbacks maintain the constancy of a certain state by transmitting a certain amount of energy from the later components of the system to the earlier ones in order to withstand the stimulus at the input of the system (interrelationship of input and output).

Under conditions of an emotional disruption of purposeful behavior, a structural decline in the constructive capabilities of the system is observed [44], which means that qualitative changes (the quality of regulation of equilibrium) occur.

The most interesting works are those in which the authors attempt to obtain experimental material to confirm the correctness of the approach to stress as a change in the balanced state of the system and activation of the mechanism for regulation of the constancy of the internal environment by means of direct links and feedbacks. For example, the works of S. A Yeremina [45, 46] view the stress state as taking the system out of a balanced physiological state. All the reactions of the system (organism) are classified as specific (corresponding to the specific features of the operating agent) and nonspecific changes or properly compensatory-adaptive processes. In this case the nonspecific changes will have

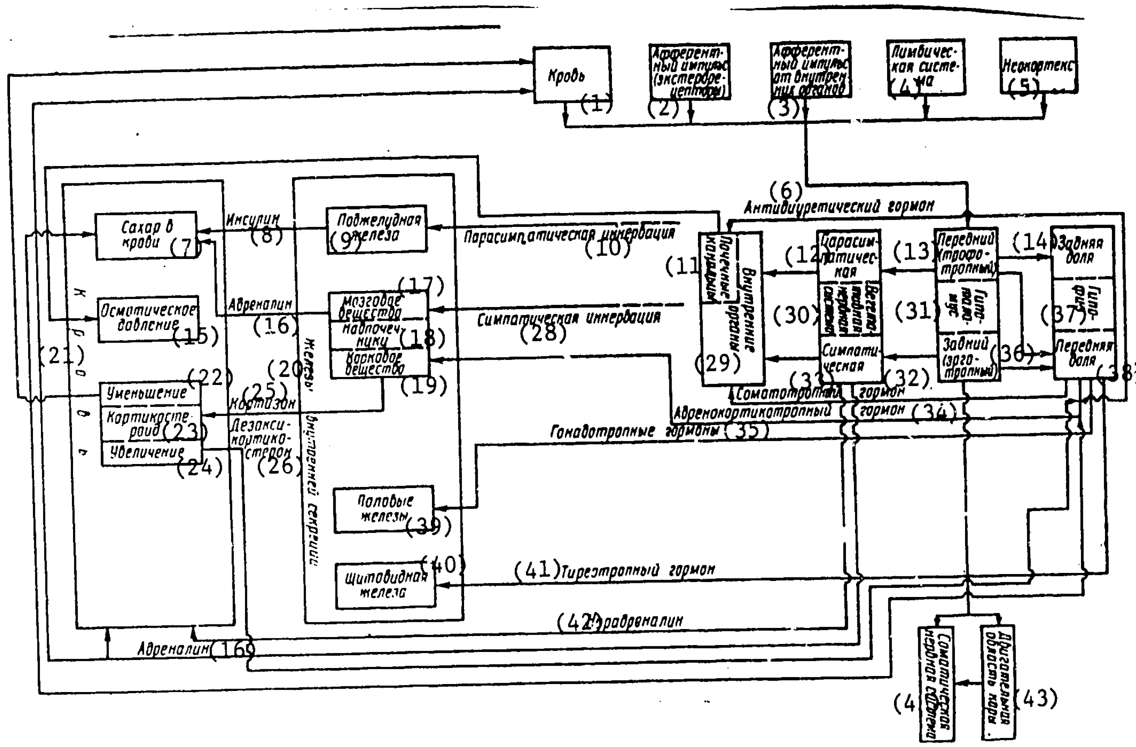

Figure 12. Complex of Neurohumeral Reactions During Stress.

Key:
(1) Blood;
(2) Afferent Pulse (Exteroceptors);
(3) Afferent Pulse from Internal Organs;
(4) Limbic System;
(5) Neocortex;
(6) Antidiuretic Hormone;
(7) Blood Sugar;
(8) Insulin;
(9) Pancreas;
(10) Parasympathetic Innervation;
(11) Tubules of Kidneys;
(12) Parasympathetic;
(13) Anterior (Trophotropic);
(14) Posterior Part;
(15) Osmotic Pressure;
(16) Adrenalin;
(17) Brain Matter;
(18) Adrenal Glands;
(19) Cortical Matter;
(20) Internal Secretion Glands;
(21) Blood;
(22) Reduction;
(23) Corticosteroid;
(24) Enlargement;
(25) Cortisone;
(26) Desoxycorticosterone;
(28) Sympathetic Innervation;
(29) Internal Organs;
(30) Autonomous Nervous System;
(31) Hypothalamus;
(32) Sympathetic;
(33) Somatotrophic Hormone;
(34) Adrenocorticotrophic Hormone;
(35) Gonadotrophic Hormone;
(36) Posterior (Ergotrophic);
(37) Pituitary Body;
(38) Posterior Part;
(39) Sex Glands;
(40) Thyroid Gland;
(41) Thyrotrophic Hormone;
(42) Noradrenalin;
(43) Motor Area of Cortex;
(44) Somatic Nervous System.

greater weight where the functional system on which the stressor is acting is more significant to the organism.

In the opinion of S. A. Yeremina, two systems are the most important components of the process of controlling the internal environment to maintain equilibrium (that is, controlling adaptive processes). These are the hypothalamus-pituitary body-adrenal glands system and the sympathoadrenal system.

Coordination of the processes of vital activity is accomplished by means of a single neurohumeral regulatory mechanism: the highest integrated centers insure adequate and rapid reactions by means of efferent synthesis. An all-encompassing generalization of regulatory influences is achieved by means of transforming the nerve pulse into local and general humeral influences.

The entire set of changes that occur during the action of a stressor on the organism has the pattern shown in Figure 13 below. Stimulation from the receptor on which the stressor acts is transmitted to the hypothalamus, stimulating the neurosecretory function o: its neurons, which is the basis of change in the functional state of the hypothalamus and activation of the pituitary body-adrenocortical and sympathoadrenal systems (the nuclei of both the anterior and posterior hypothalamus participate in regulation of the systems).

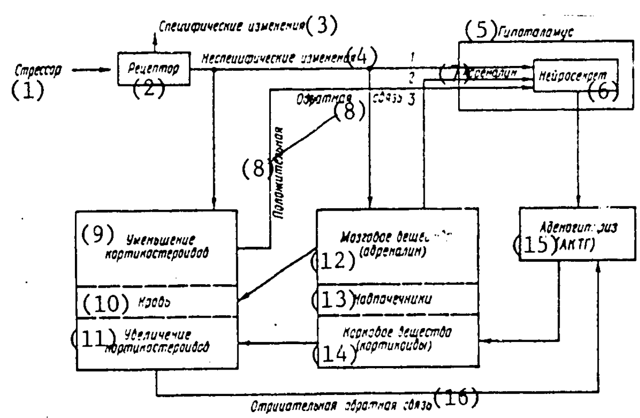

Figure 13. System of Regulation of the Neuroendocrine Cycle During the Action of a Stressor.

Key:
(1) Stressor;
(2) Receptor;
(3) Specific Changes;
(4) Nonspecific Changes;
(5) Hypothalamus;
(6) Neurosecretion;
(7) Adrenalin;
(8) Positive Feedback;
(9) Decrease in Corticosteroids;
(10) Blood;
(11) Increase in Corticosteroids;
(12) Brain Matter (Adrenalin);
(13) Adrenal Glands;
(14) Cortical Matter (Corticoids);
(15) Adenohypophysis (Adrenal Corticotrophic Hormone);
(16) Negative Feedback.

The following factors promote stimulation of the centers of the hypothalamus, which stimulates the activity of the pituitary body:

1. change in the ratio of noradrenalin and adrenalin in the direction of exhausting resources of noradrenalin and accumulation of adrenalin as the result of the arrival of the afferent pulse in the tissue of the hypothalamus;

2. the release of massive amounts of adrenalin into the blood by the brain matter of the adrenal glands and its penetration to cerebrospinal fluid and the tissue of the hypothalamus;

3. intensified absorption of corticosteroids from blood by tissue (thanks to a decrease in the bonding of the corticosteroids with blood proteins owing to the stress), which reduces the number of circulating corticosteroids and activates positive feedback.

The secretion of hypothalamic neurohumeral substance stimulates the output of adrenocorticotrophic hormone by the adenohypophysis, which in turn activates the secretion of corticosteroids by the adrenal cortex. The corticosteroids accumulate in the blood (as we have already indicated, their bonding with protein in the blood is diminished by the action of the stress factor), penetrate the hematoencephalic barrier, and inhibit the adrenocorticotrophic hormone function of the pituitary body on the model of negative feedback.

Additional information concerning this interpretation of stress in the organism as a closed system is given in the monograph by T. I. Kositskiy and V. M. Smirnov [23].

They view the system of regulation of the neuroendocrine cycle as a system of multistep linkages, which allows manyfold intensification of the action of an insignificant amount of neurosecretion by hypothalamic cells and causing general biochemical changes in all the organs, tissues, and media of the organism.

The system of multistep linkages also insures fine regulation of the level of the hormone by means of direct links and feedback in every stage. The superstructure in the form of the central nervous system is the highest integrated center. It regulates the entire cycle by means of the inhibitory system (hypocampus, singular area, and septum of the brain) and stimulation system (amygdaloid nuclei, and anterior orbital surface) (see Figure 14 below).

The material presented above permits drawing the following conclusion. The problem of stress today has become especially important. Many laboratories in our country and abroad are studying it. But many aspects of this problem are still not finally clarified and beyond dispute. Thus, a great deal has already been done to clarify the morphological substrate and functional linkages among different formations of the central nervous system which participate in shaping the stress state. But we still do not have a well-ordered theory convincingly supported by factual material for stress in the organism as a dynamic balanced system.

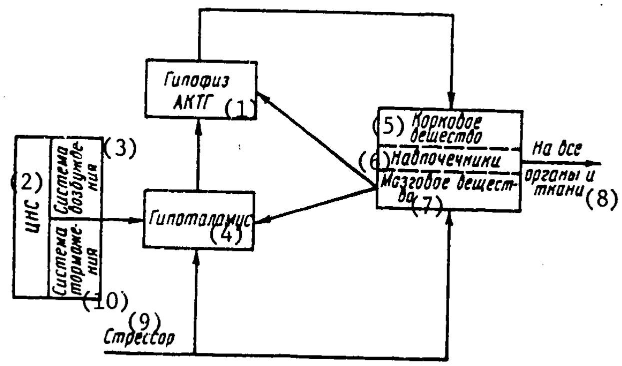

Figure 14. The Influence of the Central Nervous System on the System for Regulation of the Neuroendocrine Cycle.

Key:
(1) Pituitary Body, Adrenal Corticotrophic Hormone;
(2) Central Nervous System;
(3) Stimulation System;
(4) Hypothalamus;
(5) Cortical Matter;
(6) Adrenal Glands;
(7) Brain Matter;
(8) To All Organs and Tissues;
(9) Stressor;
(10) Inhibitory System.

If we did have such a theory it would not only offer researchers new possibilities for refining and explaining many facts, but most importantly, would outline reliable ways to normalize the organism functions that have been impaired by stress.

A second and equally important aspect that requires immediate solution is timely and reliable diagnosis of the stress state. It is common knowledge that all manifestations of the organism's vital activity are involved during the development of the state of stress: the biochemical indicators of the organism's media change, various physiological indicators undergo deviations, and changes in mental functions and behavior are observed. But can it be said that any of these manifestations of vital activity reflect the development of a state of stress fully and promptly? Of course it cannot. Some manifestations are indicative only in the critical period, while others are subject to deliberate regulation in one degree or another and still others are nullified by combination with oppositely directed changes in other elements of the same functional system. Therefore, we must find an adequate and reliable indicator of the state of stress in order to be able to influence the state and activity of a human operator working under conditions of heightened tension and to do so on a real time scale. Work is going forward with this objective, both in scientific laboratories and at actual production sites.

2. Laboratory Model of the Stress Situation

In our attempt to define operator reliability in a stress situation and objectively evaluate changes in the functional state of the operator we considered it useful to direct research in the first stage along the following path:

1. development of a method for creating stress that can be accurately calculated with respect to load under laboratory conditions;

2. determining what properties of the nervous system an operator must have to possess the greatest reserve of reliability under conditions of extraordinary stress;

3. printing out the various physiological parameters of the operator in order to identify the most informative ones.

For conducting our studies we selected one of the methods of creating operational stress under laboratory conditions, specifically the method of creating extraordinary stress owing to a shortage of time to perform the particular work assignment. We consider the method of K. K. Ioseliani and A. L. Narinskaya to be the simplest and most effective [1]. It goes as follows. Black and white numbers between one and nine are displayed in random order on a screen for the test subjects. The subject must add or subtract this number from the result of the preceding operation depending on the color of the number that has appeared on the screen. By increasing the speed at which the numbers are shown, the intensity of the subject's work can be increased greatly. A series of experiments conducted by this method demonstrated that this formulation of the problem has certain difficulties. In particular, when an error had been made it left its mark on all subsequent answers. The second incorrect action made the picture even worse, and so on. All this made it hard to calculate and differentiate erroneous actions during the full cycle of work operations. We modified this technique to eliminate the accumulation of error and correlate it with the concrete assignment. To accomplish this, the test subject had to perform the operation with the number that had appeared on the screen regardless of the results obtained from manipulating the preceding number.

The subject is told to perform more complex operations with the numbers than in the Ioseliani method, specifically, for white numbers to square them and subtract two, while black numbers are squared and three is added to the result. After a prolonged break on the screen occurs the subject must reverse the operations and perform with the white numbers those operations that had been done with the black numbers, and vice versa (switching moments). We designated these series I and series II. The subject pronounced answers out loud.

We changed the degree of operational stress by altering the speed of the film (the length of exposure of each number can vary from 1.5 to 8 seconds). In conformity with this, throughout the experiment we consider the state of the operator at moments S_1 (rate of information presentation — one number per eight seconds), S_2 (one number per four seconds), S_3 (one number per two seconds), S_4 (one number per two seconds, change of algebraic operations), and S_5 (one number per 1.5 seconds, same actions as in S_4). Figure 15 below shows the plan for presenting numbers to the subject. During the experiment the subject

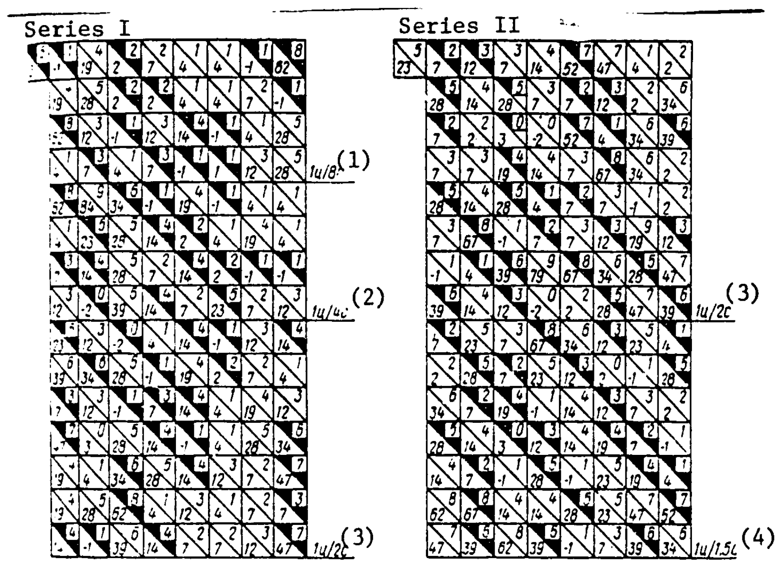

Figure 15. Diagram of Presentation of Numbers to the Subject.

Key: (1) One Number in Eight Seconds; (3) One Number in Two Seconds; (2) One Number in Four Seconds; (4) One Number in 1.5 Seconds. [Number in upper right half of each square is number shown to subject (black background indicates "black" letters). Number in lower left half of each square is result of performing operation according to instructions.]

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was seated in a specially equipped armchair in a darkened, isolated room. To provide sound isolation the subject put on ear phones and during the experiment monotonic white noise was played through them from a noise generator. The experimentor gave instructions through the same earphones. An engineering group from the division of neurobionics at the Institute of Cybernetics of the Ukrainian SSR Academy of Sciences installed a set of equipment that made it possible to create and record operational stress in the test subject (see Figure 16 below).

Considering the limited possibilities of defining all the factors that influence the reliability and efficiency of operator activity and the complex relationship between these factors and the operator's state, developers of systems to monitor the state of the operator proposed obtaining and processing a certain set of physiological indicators for the purpose of monitoring and predicting a given reliability and efficiency for operator activity.

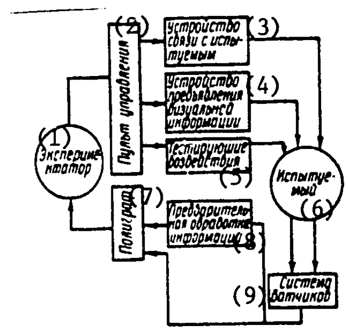

Figure 16. Flowchart of the Experimental Complex.

Key:
(1) Experimentor;
(2) Control Console;
(3) Unit for Communication with Subject;
(4) Unit for Displaying Visual Information;
(5) Test Action;
(6) Subject;
(7) Polygraph;
(8) Preliminary Data Processing;
(9) System of Sensors.

Several techniques exist today for solving the problem of automatic monitoring of the functional state of an operator. These are:

1. use of a limited set of physiological indicators that are processed by specialized computer equipment;

2. use of a broader group of physiological indicators, some of which must be processed on a general-purpose computer;

3. combining specialized and general-purpose computer equipment.

The selection of physiological indicators of the operator's state to be monitored is determined by the concrete conditions of operator activity. In many cases a dichotomous evaluation of the operator's state relative to assigned normal boundaries is adequate. The parameters of certain indicators are used for this purpose. The most frequently used indicator is the electrocardiogram, which has high diagnostic efficiency. Vast clinical experience with diagnosing pathology of cardiac activity significantly simplifies the problem of automatic diagnosis of the operator's state. The frequency and rhythm of heart contractions are used as diagnostic signs of growth of stress in operator activity. The devices that carry out the algorithms for identifying these signs are quite simple and reliable [2, 3].

In order to search for more subtle diagnostic signs of gradations of state the EKG is recorded on different information carriers for subsequent computer analysis. In this case the algorithms model the actions of a doctor in formulating the diagnosis [4] or use the characteristics of a learning matrix [5]. The problem of efficient coding of EKG signals for transmission by communications channels or storage of large arrays in compact form has been successfully resolved [6, 7, 8].

The parameters of the electroencephalogram are an important indicator of the current state of the operator during the process of information processing. Instruments for quick analysis of the operator's state based on EEG data realize algorithms of spectrum analysis [9, 10] or statistical analysis [11].

Various types of specialized devices are also used to analyze the bioelectric activity of the muscles (electromyograms), the parameters of the function of external respiration, the state of the analyzers, blood circulation, and the like [12-14].

A more precise evaluation of the operator's state requires processing a broader set of physiological indicators. For diagnosis on a real-time scale low-frequency indicators of the state of the organism are usually used. The raw data may be data from plethysmograms, pneumograms, motor reactions, pulse, the skin galvanic reaction, temperature, and so on [15, 16].

For automatic monitoring of a limited class of states specialized devices make it possible to identify sets of symptoms — combinations of informative parameters of certain functions [17] — or to make dichotomous diagnoses of the monitored parameters relative to assigned normal boundaries [6]. The automatic logical devices of these systems provide evaluation of the set of parameters according to an assigned program which is determined by their design. Analysis of high-frequency indicators under conditions where a broad class of operator states is expected requires an expansion of the capabilities of analog-digital convertors [18] and primary data processing on multichannel convertors [19] or specialized complexes [20]; another possibility is recording on magnetic tape for subsequent processing on general-purpose computers. The required computing power may be significantly lessened by a regime of semiautomatic processing of experimental results, that is, using the computer only to process data on the most distinctive stages of the transformation of state [21]. Forecasting the work capability of the operator involves a precise diagnosis of the operator's current state and requires processing a large number of physiological parameters on a real time scale.

Existing computing equipment does not permit this problem to be solved on the basis of known methods of processing biomedical data.

The experimental system developed at the Institute of Cybernetics of the Ukrainian SSR Academy of Sciences for testing the state of the operator under conditions of heightened tension of operator activity is designed to solve a number of problems: selection of parameters which are subject to monitoring; selection of methods of primary data processing to identify informative characteristics; testing diagnostic and prognostic algorithms; clarifying methods of raising the efficiency of man-machine systems, and the like.

Preliminary analysis of findings in the literature made it possible to formulate a number of requirements for systems of this class: (1) methodological universality; (2) multiparameter processing of experimental results in different regimes, including real time; (3) visual monitoring of the course of the experiment; (4) the possibility of creating feedback between the test subject and the unit which controls the complexity of the problems being solved during the experiment.

The design of the system is based on the principle of maximum use of standard biomedical equipment and available computer equipment. The system consists of a set of equipment that carries out the procedure to evoke a state of tension in the test subject and a set of equipment for recording and processing physiological indicators.

To realize the selected procedures in hardware we designed a complex consisting of equipment for the purpose of giving the test subject a certain type of assignment and equipment for communication with the subject and recording the course of the experiment (see Figure 17 below). The assignments (numbers) corresponding

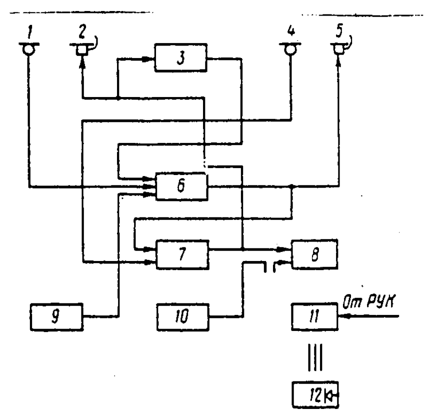

Figure 17. Flowchart of Realization of Procedure and Communication with Test Subject.

Key: (1) From Regional Switching Center.

to the experimental procedure selected were projected by a modernized Luch movie projector on a screen in a darkened room.

A marker for the beginning of displaying the number was fed to the tape of the tape recorder recording the experiment by means of special photoelectric convertor 12. The signal was produced at the moment that the marker on the movie film, a clear segment in the perforation corresponding to the start of the display, passed in front of the photocell. The action of this signal triggered a relay which with its contact closed the input to tape recorder 8 from multivibrator 10.

The equipment for communication with the subject and recording the course of the experiment consists of the following elements: a mixer to mix the signals and feed them to the headphones of the test subject, experimentor, and tape recorders that are recording the experiments; G2-1 noise generator 9; the TA-56 headphones of the test subject 5 and experimentor 2; the DEM-4M microphone of the test subject 4 and the MD-64A microphone of the experimentor 1; tape recorder 3 to delay the response of the subject (this performs the part of a programming unit).

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The mixer is two amplifier-mixers with a built-in generator (multivibrator) to feed the marker for the beginning of displaying the number to the tape recorder that records the course of the experiment. One of the amplifiers is designed to feed simultaneously white noise from the noise generator to the headphones of the test subject, the speech of the experimentor from the experimentor's microphone, and the delayed response of the subject and programmed experiment from tape recorder 3. From this amplifier-mixer the signal goes to the headphones of the test subject and the input of the second amplifier-mixer 7. The signal from the subject's microphone comes to the second input of amplifier-mixer 7. Thus, the signal at the output of amplifier 7 is a mix of the signals going to the test subject and the subject's responses. The total signal on the course of the experiment goes to the input of the tape recorder that is recording the experiment and to the headphones of the experimentor.

The level of the white noise signal was regulated individually, but it was sufficient to isolate the subject from working noise in the laboratory. A delay device realized using tape recorder 3 was devised to delay the subject's response.

To identify the psychophysiological state of the operator we recorded and processed the following indicators of functional states: EEG, EMG, SGR, EKG, reaction of opening and closing the eyes, and pneumogram. The system also envisions taking a number of other indicators of the functional state.

Recording and processing experimental data. The complex for recording and processing physiological indicators of the state of the operator consists of equipment to take readings, equipment to amplify the signals of the sensors, a computing complex, and equipment to link up with a telephone channel. Provision is made to record physiological indicators on paper tape for visual analysis of the course of the experiment. With the exception of the EEG, the physiological indicators are taken with standard sensors. The common methods of taking EEG's have certain drawbacks. A specially designed sensor was developed to eliminate the unpleasant sensations experienced by the test subject and reduce experiment preparation time. All readings were taken on a bipolar scheme. Signals from sensors $\text{Д}_1 - \text{Д}_{11}$ go to the inputs of preliminary amplifiers $\text{УП}_1 - \text{УП}_{11}$ (see Figure 18). The input series of amplifiers of an EEGU16-02 electroencephalograph was employed for preliminary amplification. Using the electroencephalograph as a preliminary amplification block makes it possible to amplify sensor signals with a high signal/noise ratio and monitor the experiment visually by recorded results on the paper tape. The ink-recording instruments C_1-C_{16} are the automatic recorders of the electroencephalograph. Amplification filter УФ, which is connected parallel to the EEG channel, and the block of filters $\Phi_1 - \Phi_5$ are designed to broaden the possibilities of visual monitoring and preliminary analysis of the EEG. They permit evaluation of the spectrum of the EEG. A standard UBP1-02 biopotential-type amplifier was used as the filter amplifier. The active low-frequency filters $\Phi_1 - \Phi_5$ were designed for the purposes of our experiment and make it possible to single out five frequencies in the band of 1-30 Hz in any combination. The preamplified signals of the sensors go to the block of output amplifiers $\text{УВ}_1 - \text{УВ}_{16}$, which amplify them to five volts and feed them to the input of the analog-digital convertor. UBP2-03 biopotential-type amplifiers were used in the block of output amplifiers.

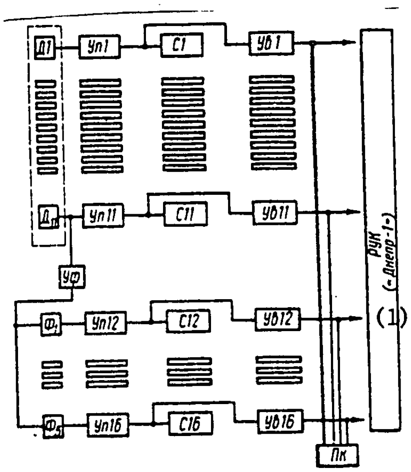


Figure 18. Flowchart of the Complex for Taking and Amplifying Physiological Parameters.

Key: (1) Dnepr-1 Regional Switching Center.

In design terms the entire complex is built in the form of two self-sufficient bays. The EEGU16-02 and equipment that realizes the procedure are mounted in one of them, while the 16UBP2-03 amplifiers with a remote monitoring console and a VK7-10A/1 digital volt meter are placed in the other. Signals on the state of the test subject are fed from the output of the preamplification complex to the regional switching center (see Figure 19 below). It consists of a Dnepr-1

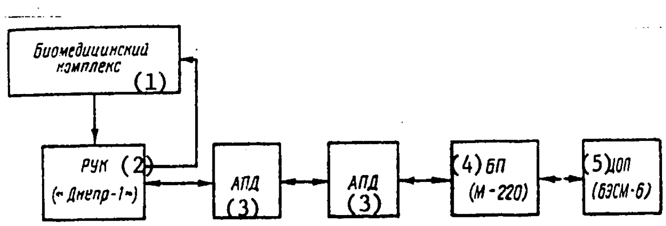


Figure 19. Flowchart of the System for Processing Biomedical Data.

Key: (1) Biomedical Complex;
(2) Dnepr-1 Regional Switching Center;
(3) Data Transmission Unit;
(4) Buffer Processor (M-220);
(5) Central Processing Processor (BESM-6).

computer supplied with a magnetic tape store which includes two tape drives with a total memory capacity of about 3 million 26-bit words. The regional switching center is connected with the biomedical complex by hardware and software. Switchable intercity communications channels are used for communication with the processing processors, which in the experiment are M-220 and BESM-6 machines. The series-produced Akkord-1200 data transmission unit is used to link the Dnepr-1 with this channel. The data transmission unit transmits data with a probability of error of 10^{-6}, which meets precision requirements for the formulation of the experiment. The data transmission unit is not designed for joint work in the computer so a special device was developed which provides a simple interface with the computer as well as automatic setting of the communications channel on instruction from the computer.

The work of the regional switching center in the mode of collecting experimental data was organized as follows. From the output amplifiers of the complex for preamplification of the parameters of the physiological indicators biomedical information goes to the input of the analog-digital convertors of the Dnepr-1 computer. The channels are queried in conformity with an assigned algorithm. The query algorithm was developed with due regard for the different frequency characteristics of the indicators and guarantees information feeding with minimum losses. Each channel is allocated a buffer zone in main memory, and when it is full information is recorded on magnetic tape. The capacity of storage allows continuous recording of physiological data for 30 minutes. After completion of the experiment the accumulated information is preliminarily processed, then the operating system of the regional switching center issues the command to establish communication and form the output file of data by parallel operation. Each output data file has a title which indicates the volume of data being transmitted, which parameter it relates to, and which processing processor it should be localized in. After communication is established the appropriate signal goes from the automatic communications instrument to the operating system and data begins to be transmitted to the processing processors. All data goes to the buffer processor, for which an M-220 is used. The buffer processor organizes the service queue in conformity with the localization priority and index for the particular communications channel and when necessary transmits to the BESM-6 central processor. Solution results go through the buffer processor to the regional switching center, where they are printed out.

Processing a limited set of physiological indicators on the Dnepr-1 in real time is envisioned to make it possible to create feedback between the test subject and the unit that controls the complexity of the assignments being solved by the subject.

Software of the experiment. The algorithms for processing indicators of the functional state of the operator are procedures for analysis of discrete and continuous processors. Discrete processing includes analysis using histograms of different orders; the functions of autointensity and cross-intensity; the logical-probabilistic method; phase monitoring; and, entropy analysis.

Processing of the continuous curves of the EEG uses algorithms for autocorrelation and cross-correlation analysis with subsequent spectrum expansion, dynamic spectral analysis, and the Carunen-Loew identification technique.

The very same set of algorithms can be used to analyze EEG's and myograms. The data is selected at different rates: the sensor query interval is five milliseconds for the EEG and two milliseconds for the EMG. Algorithms for auto-correlation and cross-correlation analysis with subsequent spectrum expansion are used to analyze spectral densities.

Correlation analysis is a powerful tool that identifies the statistical structure of a random process. But in those cases where the dominating frequency (periodic component) and power output are indicative, it is sufficient to process the EEG with discrete algorithms (finding histograms and functions of autointensity and cross-intensity). In this case the EEG is converted to a pulsed process where the pulses mark extreme points. This method is more efficient than the polar-correlation method, the phase method, and others.

Dynamic spectral analysis is based on computation of the ongoing and instantaneous spectra. It is used to study the dynamics of functional reorganizations in brain structures.

Expansion into a Carunen-Loew series is used to identify the electrograms that correspond to different functional states. The EEG's and EMG's, viewed as a random process, are expanded into the series

$$f(t) = \sum_{i=1}^{n} \lambda_i \varphi\ (t), \tag{3.1}$$

where λ_i is Eigen values, while Φ_i (t) are Eigen functions of a first-order Fredholm linear integral equation:

$$\varphi(x) = \lambda \int K(x, s)\, \varphi(s)\, ds \tag{3.2}$$

where K(x, s) is the correlation function of a random process.

The analysis algorithm involved sequential performance of two stages:

a. calculation of the correlation function by the formula

$$K(\tau) = \frac{1}{T} \int_0^T x(t)\, x(t+\tau)\, dt, \tag{3.3}$$

b. finding the Eigen functions of integral equation (3.2), which amounts to solving linear homogeneous equations of the type

$$\begin{aligned}
&(1-\lambda) y_1 + K_1(\tau) y_2 + K_2(\tau) y_3 + \cdots + K_{N-1}(\tau) y_{N-1} = 0;\\
&K_1(\tau) y_1 + (1-\lambda) y_2 + K_1(\tau) y_3 + \cdots + K_{N-1} y_{N-1} = 0;\\
&K_{N-1}(\tau) y_1 + K_{N-2}(\tau) y_2 + K_{N-3}(\tau) y_3 + \cdots +\\
&+ (1-\lambda) y_{N-1} = 0.
\end{aligned}$$

Processing the EKG requires a large set of algorithms realized using high-powered computer means. Histogram analysis, calculation of the autointensity function, and construction of integral histograms of different orders were used to analyze the EKG.

The skin galvanic reaction to emotional stress manifests itself in protracted change in skin potential (on the order of five seconds), which is exponential in character. Exponential change in the SGR is approximated by the formula $Y = H(1 - e^{\alpha}t)$, where H is defined as the amplitude value of stable exponential deviation, and α is a time constant that characterizes emotional stress. The time constant is determined by a set of points separated by intervals of 20 milliseconds. After this the averaged value $\tilde{\alpha}$ is found; to do this the mean quadratic error is calculated.

Histogram analysis of the phases of inhalation and exhalation and the respiratory cycles was done to study the basic patterns of the breathing rhythm. (The coincidence of results with different methods of statistical processing is convincing evidence of the reliability of the experimental material obtained from a comparatively small number of subjects.)

Results of investigation. The first part of our investigations was devoted to identifying the psychophysiological characteristics that insure high subject reliability in work.

The general efficiency of activity of the test subject was calculated by the formula

$$Э = \left(1 - \frac{n_{\text{общ}}}{n}\right)100\%,$$

where $n_{\text{общ}}$ is the total number of errors, and n is the number of assignments given. The efficiency of a concrete type of error was calculated by the same formula, except that the value n of the concrete error was substituted for $n_{\text{общ}}$. The experiment showed that the test subject makes mistakes that can be classified in the following categories:

1. correction (correcting an incorrect result of action announced earlier);
2. mistakes proper (incorrect result of proposed actions);
3. failure (failure to perform the assignment);
4. breakdown (series of failures);
5. refusal to go on.

The total number of mistakes included the first four categories.

Our test subjects were divided into three groups by efficiency of activity: Nos 3 and 4 who had efficiency scores of more than 50 percent; Nos 5 and 6 who had 50 percent efficiency; subjects Nos 2 and 1, whose efficiency was below 50 percent (see Figure 20a below). The subjects were men between the ages of 25 and 40, working at the same institution, with higher technical education, and in good health. The conditions of the experiment were identical for all of them.

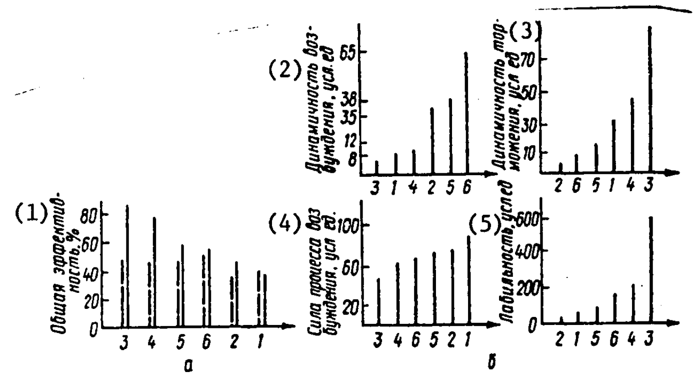


Figure 20. Distribution of Test Subjects by Efficiency of Performance of the Assignment (a) and Expression of Basic Characteristics of the Nervous System (b). (Numbers of test subjects given across bottom; dotted line shows efficiency under conditions of sound interference.)

Key:
(1) Overall Efficiency, percentage;
(2) Dynamism of Stimulation, standard units;
(3) Dynamism of Inhibition, standard units;
(4) Strength of Stimulation Process, standard units;
(5) Lability, standard units.

Using the electrophysiological method of determining the basic characteristics of the nervous system [22], we ranked our subjects by strength of the process of stimulation, dynamism of stimulation and inhibition, and lability of the nervous system (see Figure 20b). It turned out that the maximum carrying capacity in a definite type of activity is determined by the lability of the subject's nerve processes; the higher the indicator of this characteristic, the higher the indicators of efficiency.

For the type of activity which we propose the characteristic of noise resistance is very important to the human operator. The main thing is not the level of lability of nerve processes, but the strength of the nerve system in relation to stimulation. The lower the level of strength of the nervous system is, the lower noise resistance will be, and this can nullify the strong points of an operator who has high lability of the nervous system and outstanding work indicators in the absence of distracting factors (see Figure 28). The obvious explanation for this is that a strong nervous system produces a stable dominant center in the cortex of the large hemispheres when performing an assignment, and outside stimuli cannot break it down [23, 24]. But a weak nervous system cannot counteract the influence of outside stimuli, which act as an external inhibitor.

The transition from the first series of tests to the second (where actions with white and black colors were changed to their opposites) enabled us to study one more important characteristic of the operator, ability to switch. On the basis of our findings we can assert that ability to switch is even more closely bound to level of lability of nerve processes than maximum carrying capacity. This conclusion agrees with the opinion of many other researchers [25].

In the next stage of experimental work we analyzed changes in various physiological indicators during the period of development of extreme stress in the test subject.

Changes in the EEG. The results of EEG analysis showed that during the period of the stress state the most distinctive change was in the Alpha rhythm: its index and intensity declined. The more complex the situation became, with a faster pace of work and introducing the switching elements, the more strongly this phenomenon was expressed. An intensification of the Theta rhythm (see Figure 21 below) was noted at moments of extreme stress. In a series of tests the intensity of the Beta rhythm definitely increased (almost three-fold compared to the initial level) for test subject No 3 (the most "reliable").

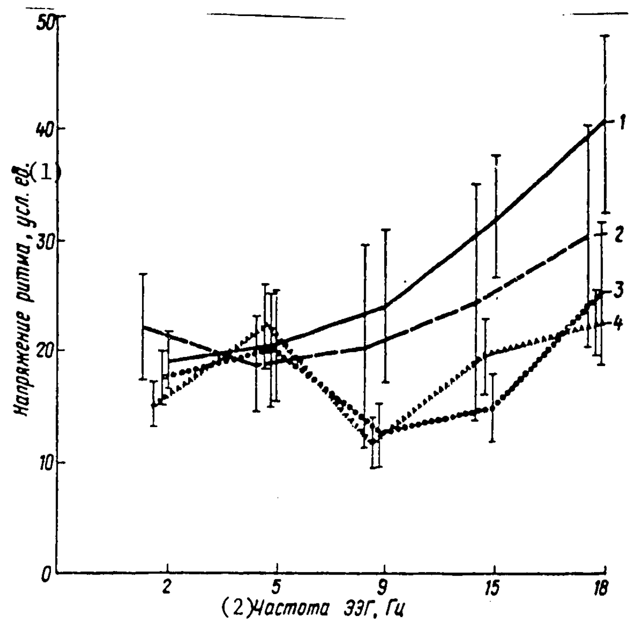


Figure 21. Change in the EEG of Subject No 3 During Intensive Work (1— before film; 2 — after film; 3 — film, series I; 4 — film, series II).

Key: (1) Intensity of Rhythm, standard unit;
(2) Frequency of EEG, Hz.

Individual differences in EEG deviations were most clearly expressed during the period of recovery after completion of the work. The subject who had a significantly strong nervous system in relation to stimulation and comparatively low lability of nerve processes underwent a prolonged after-effect and gradual restoration of the initial level of the Alpha rhythm. In the other subjects the Alpha rhythm was restored almost immediately after the film ended, and in some cases the index and intensity of this rhythm exceeded their initial level, indicating exaltation.

Additional information was taken from analysis of the EEG reaction of assimilating rhythm. It was found that during intensive work the most "reliable" operators (Nos 3 and 4) had high indicators for assimilation of the Beta and Alpha rhythms; the least "reliable" (Nos 1 and 2) had a low level of assimilation of the Theta rhythm, but in a number of tests their assimilation of the Beta rhythm increased. In addition, the general induction effect was higher for the "reliable" operators than for the less "reliable" ones.

Changes in breathing. In view of the specific features of our experiment we cannot form judgements on the "pure" influence of the nature of the functional state on changes in breathing. A significant share of the changes were a result of the need to pronounce the result of the calculation out loud. The need to simultaneously maintain the functions of pulmonary gas exchange and create an acoustic effect was the cause of the distinctive pictures of speech-related breathing (see Figure 22 below). Therefore, the parameter of frequency of breathing appears to

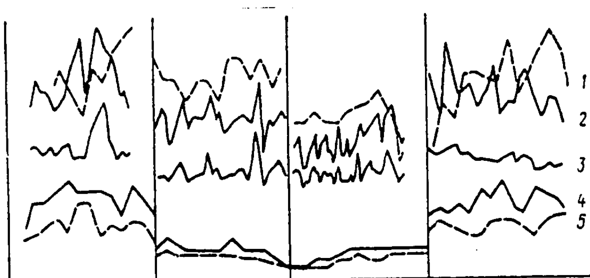


Figure 22. Dynamics of Muscle Movements, Respiratory Cycles, and Cardiac Rhythm During Performance of the Assignment: (1 — number of blinking motions, interval of 10 seconds; 2, 3 — length of exhalation and inhalation in standard units; 4, 5 — maximum and minimum distances between R waves of the EKG at 10-second intervals).

Key:
(1) Initial State;
(2) Series I;
(3) Series II;
(4) After Performance of Assignment;
(5) Time of Experiment.

be an indicator of the pace of work and most likely depends on the rate at which frames are shown, not on change in functional state. It should be noted that when assignments were displayed at low rates, the rate of breathing could still be found under the control of the subject and was, so to speak, an expression of the subject's style of work (stretching out the answer, getting set for the beginning of the next frame, and so on). At a high working speed the frequency of breathing increased and was entirely governed by the rate at which assignments were given.

We can note the following changes in indicators of breathing, which reflected the functional state of the subject: decrease in the ratio of the lengths of inhalation to exhalation owing to progressive shortening of inhalation; the appearance of delays in breathing at moments when unexpected stimuli were expected (instructions, the beginning and end of work, functional tests, and the like). On some occasions here it was possible to record an EKG on the plateau of protracted respiratory movement.

The dynamics of blinking motions. Analysis of experimental findings showed that blinking motions can be a rather sensitive indicator of growth in tension in the subject. The second valuable feature is the precise interrelationship between the number and form of blinking motions and the attention function. At those moments when the subject's attention was engaged (waiting, switching on the film) or concentrated on a certain type of activity (problem-solving) blinking motions decreased sharply in frequency or practically stopped. Only when the activity was completed or almost simultaneously with the spoken answer was a precise blinking motion of the forms specific to each subject recorded.

Changes in the number of spontaneous oscillations of the SGR. The skin galvanic reflex is a generally recognized indicator of stress. Owing to the procedure we adopted, we recorded only spontaneous oscillations of the SGR. By analysis of change in the number of these oscillations before and during subject performance of an assignment demanding significant intensity, we were convinced of the fairly high sensitivity of this parameter (see Figure 23 below).

Changes in the EKG. In our analysis of the electrocardiogram we observed that intensive activity caused changes which may provide evidence of the development of a state of stress. The most frequently encountered changes were the following: increase in the height or density of the P and T waves, splitting of these waves or the appearance of two-phase modifications of them, and a shift in the segment S-T relative to the isoline. In some subjects the interval P-Q increased and extrasystolia was observed.

Interesting results were obtained by calculating the frequency of heart contractions at 10-second intervals. As the stress of the subject increased we recorded a significant increase in the frequency of heart contractions (from 60 to 150 beats a second [sic]), and a significant decrease in the degree of arrhythmia, which was defined as the difference between the maximum and minimum pulse intervals in a given time segment (10-second intervals) (see Figure 22). Summarizing what has been presented above, it must be observed that according to our analysis of the activity of the test subjects on the assignments using our proposed methodology, the subjects who did best were those who had the highest lability of nerve processes. In the presence of distracting stimuli, however, the most important characteristic of the nervous system for successful activity was strength in relation to stimulation. Thus, our research showed that it is not possible to standardize any one characteristic of the nervous system for purposes of vocational selection [26, 27]. It is wiser to agree with those researchers who believe that optimal efficiency in a particular type of activity requires specific characteristics of the operator's nervous system [28]. Operational stress includes not only the work indicators of the subjects, but also their functional

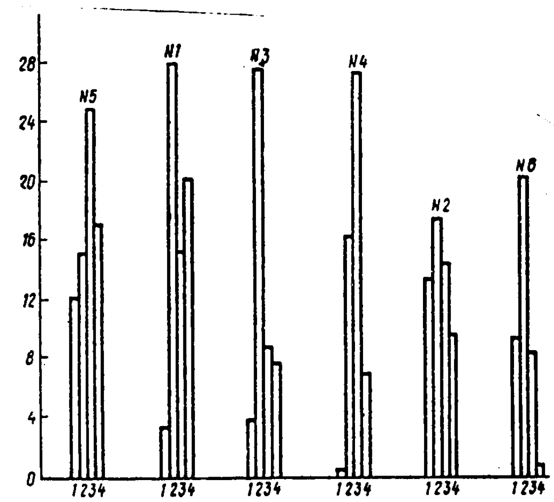


Figure 23. Change in the Number of Spontaneous Oscillations of the SGR During Performance of an Assignment (1 — before performance of the assignment; 2 — during film series I; 3 — during film series II; 4 — after performance of the assignment [numbers on top of columns indicate individual test subjects]).

state, which we judge by change in the parameters of activity of different systems of the organism.

Comparing the data from our analysis of change in the EEG's of test subjects with data described in the specialized literature, one may conclude as follows. We and other investigators [28] are inclined to the opinion that there is no one, uniform EEG expression of the state of stress in a human operator. In the first place, the picture of change depends on the degree of stress (the initial stages are characterized by a decline in the index and intensity of the Alpha rhythm, then as stress grows, the activity of the Beta and Theta rhythms in the EEG increases); in the second place, individual differences introduced considerable variability. The latter point is related to the basic characteristics of the nervous system of the subject, and is seen clearly in our experiment. The literature points out that during stress situations one may observe intensification of Beta activity [29, 30], weakening of the Alpha rhythm [28], and change in both slow and fast rhythms [28, 31]. But this diversity of changes does not correlate strongly with the basic characteristics of the subject's nervous system and the degree of stress.

The reaction of Alpha activity and intensification of the Beta rhythm observed in our experiments were probably caused by activation of the stem reticular formation during the state of stress [32]. Intensification of the Theta rhythm in certain cases, especially when the pace of work picks up, may be related to intensification of the inhibitory process as the result of the development of mental fatigue [33].

While tracing changes in the pneumogram, we observe an increase in the frequency of the respiratory rhythm, which occurred mainly as the result of shortening of inhalation. Breathing became more regular as stress grew. In part these changes may have occurred as the subject adjusted to the increasing pace of spoken responses. But in our opinion, the principal contribution to these changes was made by a change in the functional state of the subject. This is illustrated by the recording of EKG oscillations on plateaus of respiratory movements at moments of significant stress and by the shortening of inhalation in relation to exhalation [34].

Analysis of the blinking motions of the subject produced interesting findings. The feature we discovered, that blinking motions precede a spoken response (by up to 1.5 seconds) enables us to recommend this indicator as one of the first manifestations of decision-making. This may possibly prove very useful to those investigators who, owing to the nature of their job, must clearly identify the central time of making the final decision. It seems to us that recording blinking motions permits a more exact estimate of these moments than recording other motor reactions (spoken response, pressing a button).

When comparing our findings with data available in the literature, the following must be observed. We cannot agree with the view of certain investigators [35] that concentration of attention entails an increase in the frequency of blinking motions. We are inclined to assert the opposite. The reason for these different views is possibly that the above-mentioned authors, when giving the operator an excessive load and recording an increase in the number of blinking motions, considered it self-apparent that the operator must have experienced an intensification of attention. But it follows from the description of the type of activity and errors made during it that the procedures used by the investigators led to disorganization and dispersion of attention, and this was expressed indirectly by an increase in the frequency of blinking.

Thus, we consider it more accurate to say that there is a negative correlation betw n the frequency of blinking motions and the attention function.

Analysis of spontaneous oscillations of the SGR confirmed their high sensitivity relative to reflecting growth in operational stress. But we noted the absence of a linear dependence of this indicator on degree of stress. Thus, in the second film series when stress continued to grow, the indicator of spontaneous oscillations of the SGR was often lower than in series I (see Figure 23 above).

It is possible that this contradiction can be explained by the fact that in the first series, when stress was lower, there may have been self-control of state which exercised an additional influence on the SGR. But owing its high pace, the second series did not allow the subject time for self-control, but rather "automated" the subject's activity and this, in many cases, slightly lowered the number of spontaneous oscillations of the SGR.

Analysis of change in the pulse and EKG of the test subjects before and during work convinced us that the procedure employed was highly efficient to create a state of extraordinary stress. Evidence of this is seen in the flattening of the T-wave, the elongation of the T-Q interval, the shifting of the segment S-T in relation to the isoline, and extrasystolia. A number of works [26, 29, 36-39] have described these changes as reliable indicators of stress. These works testify to significant changes in the functions of the automatism, conductivity, and stimulatability of the cardiac muscle and to its trophism.

The degree of pulse arrhythmia is a good indicator of change in the level of stress. This quantity reflects individual characteristics more precisely than other indicators and is evidently linked to the central mechanisms for regulating autonomous functions. Thus, in most of our subjects arrhythmia was practically zero at the moment of greatest stress. But in subject No 5 it was well expressed even at critical moments. We became convinced that this difference was linked to the intimate mechanisms of regulation by an analysis of graphs constructed from cardiac interval diagram data in the inhalation-exhalation test. The curve of subject No 5 differs from the curves of the others (see Figure 24 below). Whereas the curve of subject No 4 may be cited as an example of plastic

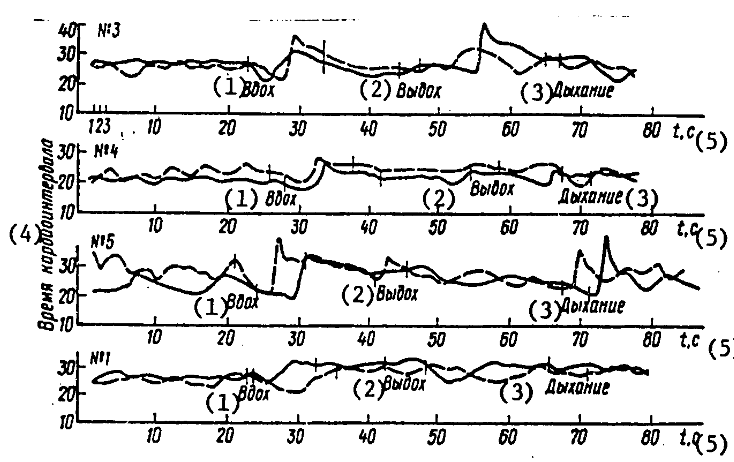


Figure 24. Change in the Cardiac Interval Diagram for the Inhalation-Exhalation Test Before (——) and After (– – –) Performance of the Assignments for Subjects Nos 3, 4, 5, and 1.

Key: (1) Inhalation;
(2) Exhalation;
(3) Respiration;
(4) Time of Cardiac Interval;
(5) Time, seconds.

adaptation of cardiac activity to a changed situation, the curve of subject No 5 demonstrates the opposite type of reaction, reactive. This is obviously directly related to the large range of frequencies of heart contractions maintained by subject No 5 even during moments of heightened stress which, judging by the other subjects, demand maximum rhythm.

As a result of statistical processing of the experimental material it was found that the most informative indicators of growth in operational stress of the operator are quickening of the pulse, decline in the variability of the cardiac intervals, increase in the total area of oscillations of the SGR, decrease in the alpha index and area of alpha activity of the EEG, and decrease in the total area of all rhythms of the EEG.

In conclusion, we would like to present the following considerations. In our opinion, traditional methods of analyzing physiological experimental materials do not allow sufficiently complete extraction of information from the organism reactions that are recorded. These methods "work" well when we are dealing with a stable, steady state. In the case of great variability of reactions when the state is undergoing rapid changes, if we use conventional methods of analysis we lose very important nuances of the transitional states by attempting to attain the essential reliability. For this reason investigators are increasingly resorting to the methods of cybernetics, automatic regulation theory, information theory, mass service theory, and the like. At the present time there are already a number of works in which different facets of vital activity are considered from the standpoint of systems organization [31, 40-45].

It is evident that even a state of extraordinary stress can be considered from the standpoint of the structural systems approach. The first attempts in this area have already been made [46, 47]. This approach makes it possible to apply the methods of classical automatic regulation theory to the study of this state. Thus, the method of transitional characteristics can be used successfully to analyze the response reactions of the organism to short-term test stimulation (flashes of light, tactile stimulation). When we consider the potentials in the EEG and SGR to a concrete stimulus evoked by a flash of light and view the cardiac interval diagram in the inhalation-exhalation test as a system deviation in response to a short-term disturbance, we can judge the quality of regulation in the central nervous system at the particular moment of the person's activity.

The experimental findings we have made also provide material for frequency analysis, which is used in automatic regulation theory in cases of steady oscillatory practices.

Thus, it was shown in Figure 22 above that the changes in the physiological indicators represented are oscillatory, and different spectra, magnitudes of oscillations, and "base" levels correspond to different functional states.

It appears possible to analyze the stability of a system in its initial state and as the stress on the subject grows until the subject refuses to continue the activity. This quality of the system can be determined by means of the reaction of assimilating rhythms, assuming that when a system is more stable there is less possibility of inducing some particular rhythm in it.

3. Studying Operator Reliability in a Real Situation

From our investigation of stresses created under laboratory conditions we moved on to study difficult states of the operator in real ASU's [automated control systems], in particular to the study of operators of ASU's for galvanizing production. This system employs a three-level hierarchical structure (control computers — autonomous unit for linkage with the object — local automation of galvanizing lines). This makes it possible to work in the automatic, semiautomatic, and manual regimes and gives the system a high degree of continuity of service.

The ASU operator performs the following functions: preparing the system for operation, receiving and feeding raw data to the system, checking the schedule produced by the control computer and sending documents to the work positions, launching the system in the automatic control regime, observing the course of execution of industrial processes, managing industrial processes in the semiautomatic control regime when necessary, identifying and eliminating malfunctions, and preventive maintenance of the system.

Operator work in the semiautomatic regime deserves special attention. This regime is used in emergency situations and in the case of a malfunction in the control computer for the purpose of completing industrial processes that have been begun or carrying out the shop's production program.

When working in this regime, operators themselves must compile the schedule of industrial processes to process the essential parts and independently control the course of processing by means of the unit for linkage with the object. This situation greatly increases the responsibility of the operator, which gives rise to significant mental stress and is reflected both in how the operator feels and in the productivity of the operator's labor. It was precisely this circumstance that led our work to study the activity of the operator in emergency situations when system work is switched to the semiautomatic regime.

After mastering the occupation of operator (by studying the technical documents and actually working at the console of the linkage unit) and studying the results of a survey of leading specialists, we wrote up a functional model of work in the semiautomatic regime based on a specific man-machine system, the "Gal'vanik" [galvanizing worker] ASU (see Figure 25 below). Based on this model we formulated the problems for our investigation:

1. what effect do operator characteristics have on labor productivity?

2. what effect does the functional state of the operator have on labor productivity?

3. what effect do operator characteristics have on the functional state of the operator?

In the present work we will consider the first question.

The following indicators were chosen as criteria of the quality of operator labor in the semiautomatic regime: knowledge of the industrial routes and exposure time of the parts being processed (which influences development of the optimal schedule for efficient loading of industrial lines), behavior during emergency situations on the industrial line, and the presence of mistakes in receiving incoming information on orders, making decisions, and carrying out

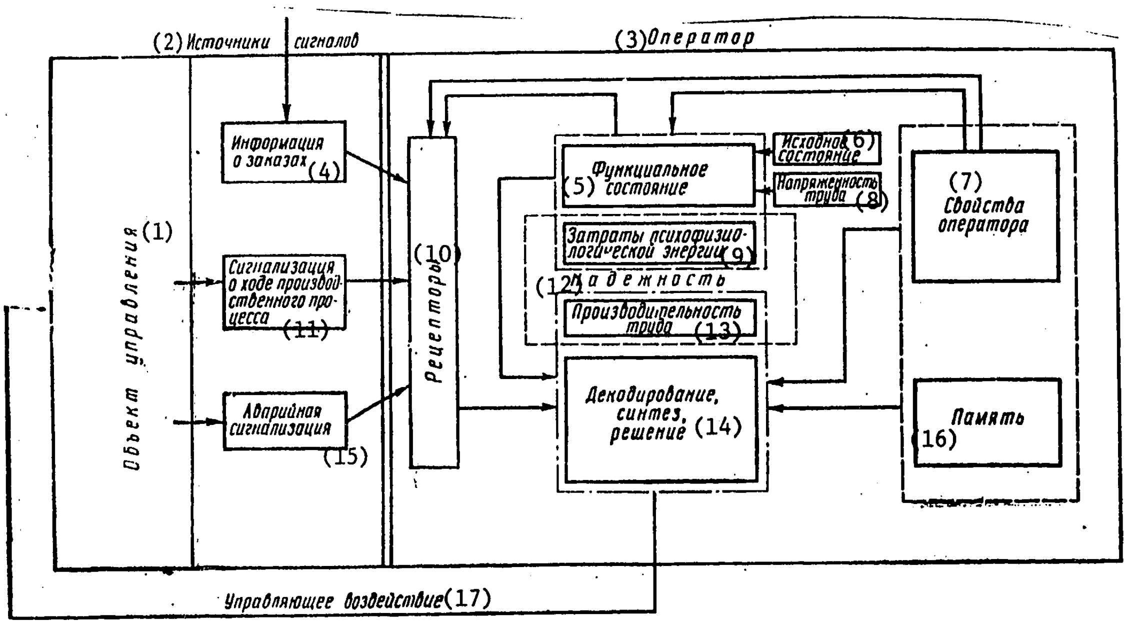


Figure 25. Functional Model of a Man-Machine System Applicable to the "Gal'vanik" ASU.

Key:
(1) Control Object;
(2) Signal Sources;
(3) Operator;
(4) Information on Orders;
(5) Functional State;
(6) Initial State;
(7) Operator Characteristics;
(8) Intensity of Labor;
(9) Expenditures of Psychophysiological Energy;
10. Receptors;
11. Signals on Course of Production Process;
12. Reliability;
13. Labor Productivity;
14. Decoding, Synthesis, Decision;
15. Emergency Signals;
16. Memory;
17. Control Action.

control actions. After evaluating the work of each operator in the semiautomatic regime by these criteria, we divided them into two groups: "reliable" and "unreliable." Then we began our investigation of the characteristics of each operator. We began here from the need for a detailed consideration of characteristics in three aspects: sociological, psychological, and physiological.

We developed a special questionnaire to ascertain the characteristics and qualities of the individual operator in the sociological aspect. In each concrete investigation the specific nature of its objectives and problems necessitate independent development of such a questionnaire (or fundamental adaptation of a questionnaire developed earlier).

Our questionnaire was designed to identify character traits, social consciousness, motives and interests in production activity, breadth of outlook, feeling of satisfaction, and sensation of the symptoms of fatigue and overfatigue, that is, the basic moving forces ("output") that guide the actions of a person working in a particular production sphere.

The questionnaire blank consists of four parts:

1. personal information (demographic data on the subject);
2. statement to the test subject for the purpose of preparing the subject for the investigation;
3. the questions proper;
4. evaluation table and "keys."

The questions are put in indirect form, that is, they relate only indirectly to a particular characteristic. The questions identify behavioral correlates of the characteristic under study. The questions are "closed," in the sense that the subject must answer with one of the alternatives given. From our point of view this questionnaire makes it possible to clarify the following matters.

I. Practical qualities (qualities relating to public activity and work):

1. initiative (inner inducement to new forms of activity, enterprise, leadership role in certain actions, innovativeness);

2. prudence (ability to foresee possible results and events in the future, endeavor to prepare for possible changes);

3. demandingness (making high demands on someone or something, strictness, high standards, and persistence);

4. scrupulousness (precision to fine points, extreme carefulness).

II. Impulse-volitional qualities (balance between involuntary impulsive action and behavior and the possibility of conscious, volitional control of them):

1. discipline (acceptance of discipline, consciousness of personal and public duties, obedience to established order);

2. decisiveness (boldness, readiness to make and carry out a decision, firmness in actions, steadfastness, inflexibility);

3. self-control (patience, firmness, self-possession, consistency, and absence of temper and irritability);

4. aggressiveness (forceful-aggressive character, endeavor to force subordination to one's will);

5. recklessness (excessive bravado in behavior, neglect of safety precautions out of bravado).

III. Moral qualities (attitude of the individual toward generally accepted social norms of behavior):

1. sense of honor (social-moral dignity, honesty, adherence to the "word of honor," pride, and personal dignity);
2. consciousness (honest performance of one's duties and obligations);
3. principle (unfailingly guided in action by firm principles and fundamental beliefs);
4. sensitivity (empathy, sympathy);
5. modesty (restraint in revealing one's strongpoints and accomplishments, moderation and order in the way of life and behavior);
6. egotism (narcissism, preference for one's personal interests to those of others, neglect of the interest of society).

IV. Qualities that determine motives of behavior:

1. ambition (excessive hunger for honors, aspiration to a position of honor);
2. purposefulness (existence of a clear goal).

V. Qualities that determine attitudes toward the world around:

1. curiosity (inquisitiveness, inclination to acquire new knowledge);
2. optimism (cheerful and lively attitude toward the world, permeated with faith in the future and in success).

VI. Social consciousness:

1. attitude toward labor as purposeful and socially useful activity that requires mental and physical exertion; labor enthusiasm and accomplishments;
2. attitude toward moral norms (ethical precepts, rules that define behavior, and spiritual qualities necessary to a person in society);
3. collectivism (adherence to the principle of common interest, the collective principle).

VII. Vocational motives (instigating factors, factors to substantiate the choice of an occupation).

VIII. Production interests (significance and attractiveness of production activity).

IX. Breadth of outlook (volume of knowledge, experience, and interest):

1. professional experience (aggregate of professional habits and skills acquired in practice);
2. experience of life (aggregate of rules and habits of everyday life acquired in practice);
3. cultural level (social and intellectual development).

X. Level of satisfaction (feeling of satisfaction experienced by persons working to meet their needs and carry out their wishes and aspirations):

1. with one's self;
2. with the production collective;
3. with the particular production site;
4. with one's material welfare and living conditions.

XI. Existence of symptoms of fatigue:

1. fatigue;
2. overfatigue;

XII. Falsehood indicator (desire to appear better than one really is).

The falsehood indicator is introduced so that the investigator can know how far to trust the test subject's answers, how sincere the subject was.

In writing up the form we used the advice given in works [1-6].

Questionnaire Form

(Developed in the division of neurobionics of the Institute of Cybernetics of the Ukrainian SSR Academy of Sciences)

1. Full name.
2. Sex.
3. Year and date of birth.

4. Party membership.

5. Education.

6. Occupation.

7. Family status (number of persons in the family, number of children).

8. Living conditions (common or separate apartments, area, communal facilities).

9. Material support (how many rubles per family member).

10. State of health (existence of chronic illnesses, frequency of illness-related absence from work).

11. Who in your production collective knows you well?

12. Who in your production collective do you know well?

Esteemed Comrade!

The present study is being done for scientific and practical purposes. Test results for individual subjects will not be made public at any time.

The objective of the study is to give recommendation for better organization of labor at your enterprise. Your answers will help us in this. During the testing process you can learn more about yourself. A rational schedule of labor and rest for you will be recommended.

We invite you to participate in this work. Address it, please, with full seriousness. Answer the particular questions in the questionnaire as truthfully as possible. Participate actively and conscientiously in this proposed study. The correctness and accuracy of the final results will depend entirely on the sincerity of your answer. We thank you in advance.

Instructions

The questionnaire consiste of 112 questions. The time for answering them is unlimited. But we advise you not to think at length about the answers because in most cases the experimenter needs your first reaction to the question. A number of alternative answers are given in the form for each question. You must select those choices which correspond to your answer (mark them with a check). Questions cannot be skipped.

Questions

1. Have there been cases where you were the initiator of some measure, job, or innovation?

(1)	fairly often;	(2)
(2)	I remember 1-2 cases;	(1)
(3)	No, I do not remember any cases.	(0)

2. Before undertaking a job do you always think over the results it may bring?
   (1) Yes, always; (2)
   (2) Sometimes I do; (1)
   (3) No, I do not. (0)

3. Are you strict with yourself and other people? Do you always demand that things be done properly?
   (1) Yes, always; (2)
   (2) Sometimes; (1)
   (3) No, I am not strict or demanding. (0)

4. Do you try to investigate any job down to the fine points, even if you know that you will not be working on it later?
   (1) Yes, of course; (2)
   (2) Not always; (1)
   (3) No, I do not. (0)

5. Do you obey established procedures in production absolutely?
   (1) Yes, always; (2)
   (2) Not always; (1)
   (3) No. (0)

6. If you have decided to do something, do you act decisively and carry it out?
   (1) Yes, of course; (2)
   (2) Not always; (1)
   (3) No, I always lack the determination. (0)

7. Are you always outstanding for self-control in difficult situations? Is it typical of you never to do anything in anger?
   (1) Yes; (2)
   (2) There are cases where I lose self-control; (1)
   (3) No, I often act from anger. (0)

8. Do you dislike it when you are contradicted if you are sure you are right?
   (1) Yes, absolutely. (2)
   (2) There are such cases; (1)
   (3) No, I always listen to objections. (0)

9. Do you like to amaze people by your daring, even when it involves risk?
   (1) Yes, very much. (2)
   (2) There have been such cases; (1)
   (3) No, I do not. (0)

10. Do you think that if you have given your word of honor you should not break it in any case?
   (1) Yes, of course; (2)
   (2) Depending on circumstances; (1)
   (3) No, I do not think so. (0)

11. Do you think that when you have begun a job you are obligated to finish it and do it well?

(1)	Absolutely;	(2)
(2)	The main thing is to finish, but not necessarily well;	(1)
(3)	It may be possible not to finish if unforeseen obstacles arise and there will be no punishment for this.	(0)

12. Are your convictions on many issues of principle so strong that you never go against them?

(1)	Yes they are;	(2)
(2)	In some situations principles can be forgotten;	(1)
(3)	One must do what others do.	(0)

13. Do you set aside your affairs (even matters very important to you) if some one is in trouble and needs your help?

(1)	Yes, always;	(2)
(2)	Only if I am absolutely sure that I can help;	(1)
(3)	Only if it will not cause me great unpleasantness.	(0)

14. Do you think that you must tell of your achievements yourself, and not wait until others notice them?

(1)	Absolutely;	(0)
(2)	Sometimes;	(1)
(3)	No, I do not.	(2)

15. Do you notice that your personal interest hinders you from participating actively in public activities?

(1)	Yes, this happens often;	(0)
(2)	Such cases rarely occur;	(1)
(3)	No, I cannot remember such a case.	(2)

16. Do you find it very pleasant to be praised? Is this one of the reasons that makes you try to work better?

(1)	Yes, I like it very much when I am praised;	(2)
(2)	Yes, it is pleasant but I do not strive for it;	(1)
(3)	No, it doesn't matter to me.	(0)

17. Do you have a clear major goal in life to which you subordinate all your actions and behavior?

(1)	Yes;	(2)
(2)	I have some aspirations, but I cannot say that I have one single goal;	(1)
(3)	I have not thought about this.	(0)

18. Do you have a constant desire to learn new things? For this purpose do you read many books, watch television, go to lectures, and the like?

(1)	Yes, always;	(2)
(2)	Sometimes I have a strong interest in things;	(1)
(3)	No, I am only interested in what I need for work and homelife.	(0)

19. Do you often have a good attitude, positive and cheerful?

(1)	Yes, almost always;	(2)
(2)	No, sometimes I am in a bad mood and nothing makes me happy;	(1)
(3)	I am very rarely in a good mood and cheerful.	(0)

20. Do you think that each member of society should engage in socially useful labor (regardless of the material reward)?

(1)	Yes, of course;	(2)
(2)	I'm not sure;	(1)
(3)	Only if the person wants to or needs to.	(0)

21. Do you think that social norms of behavior should be followed by all persons at all times?

(1)	Yes, of course;	(2)
(2)	In some circumstances they can be ignored;	(1)
(3)	No, I do not think so.	(0)

22. Do you think that a collective of people is a powerful force that can handle any task?

(1)	Yes, of course;	(2)
(2)	Sometimes;	(1)
(3)	No, I do not.	(0)

23. Did you choose your present job because it has any of these advantages:

(1)	Closeness to the place of residence;	(1)
(2)	Small workload;	(1)
(3)	Clean work;	(1)
(4)	Availability of institutional child care and nursery schools;	(1)
(5)	Possibility of receiving an apartment;	(1)
(6)	____________________ (if the list has omitted a factor which led you to choose the job, write it in the blank).	(1)

24. Do you like your occupation enough that you have decided to devote your entire life to it? If you were able to choose your occupation again, would you choose the same one?

(1)	Yes;	(2)
(2)	Possibly;	(1)
(3)	No.	(0)

25. What professional training have you?

(1)	Graduation from secondary school, without vocational education;	(0)
(2)	Graduation from tekhnikum or specialized school;	(1)
(3)	Graduation from a higher educational institution.	(2)

26. What is your experience of life?

(1)	Less than 30 years old;	(1)
(2)	More than 30 years old;	(2)
(3)	Living separate from parents since the age of 20 or more;	(1)
(4)	Living separate from parents from the age of 17 or less;	(2)
(5)	Do not have (have not had) your own family;	(1)
(6)	Have (had) your own family.	(2)

27. Do your interests and knowledge concern only your specialization, or

(1)	Are you knowledgeable about and interested in painting (often visit museums, collect slides, reproductions, and literature on painting);	(1)
(2)	Are you unfamiliar with and uninterested in painting;	(0)
(3)	Do you like the theater, and are you knowledgeable about it and familiar with the repertoires of theaters in your city and leading theaters in the country;	(1)
(4)	Are you unfamiliar with the theatrical life of your city and country?	(0)

28. Do you often feel dissatisfied with your behavior in solving certain problems, during arguments, and the like.

(1)	Yes, all the time;	(0)
(2)	Sometimes I feel that way;	(1)
(3)	No, I do not feel that way.	(2)

29. Do you think that your production collective is a strong and unified collective which can handle any problems of production organization and molding character?

(1)	Yes;	(2)
(2)	I am not completely sure;	(1)
(3)	No.	(0)

30. Do you think that your production site has good organization of labor and correct selection and placement of personnel?

(1)	Yes;	(2)
(2)	Not entirely;	(1)
(3)	No.	(0)

31. Do you think that your wages are the maximum that you can earn? Do you think that you should change your place of work in order to make more?

(1)	I am satisfied with my wages;	(2)
(2)	I would like to earn more, but I do not intend to change jobs for this reason;	(1)
(3)	I am not satisfied with my wages and for this reason intend to take a new job.	(0)

32. Do you notice that you experience fatigue where you did not before with heavy workloads, and sometimes even with ordinary workloads?

(1)	Yes, all the time;	(2)
(2)	Sometimes;	(1)
(3)	No, I do not.	(0)

33. Do you notice that your work capability has declined sharply and your memory and attention have weakened noticeably?

(1)	Yes, I notice this all the time;	(2)
(2)	Sometimes I notice it;	(1)
(3)	No, I do not.	(0)

34. Do you always keep your promises in all circumstances?

(1)	Yes, always and in all circumstances;	(1)
(2)	No, not always.	(0)

35. Do you try to do any job that you have undertaken more simply, quickly, and economically than is customary?

(1)	Yes, definitely;	(2)
(2)	If there is such a challenge;	(1)
(3)	No.	(0)

36. If you have undertaken some job, before beginning do you think over what you will need to do it and outline a clear plan of action?

(1)	Yes, always;	(2)
(2)	Sometimes I do not;	(1)
(3)	No.	(0)

37. Are you careful in choosing friends, partners at work, and acquaintances?

(1)	Yes, of course;	(2)
(2)	Not always;	(1)
(3)	No, I am not.	(0)

38. Do you ever have thoughts that you would like to conceal from others?

(1)	No, never;	(1)
(2)	Sometimes.	(0)

39. Do you perform everything you undertake very carefully, down to fine points, even if there is no need for it?

(1)	Yes, always;	(2)
(2)	Sometimes;	(1)
(3)	No, if there is no need I do not do it carefully.	(0)

40. Do you notice a slight decline in your work capability? Is it sometimes difficult for you to concentrate? Have you been forgetful?

(1)	Yes, I notice these things all the time;	(2)
(2)	They sometimes occur;	(1)
(3)	No.	(0)

41. Do you follow all the requirements of public order without exception?

(1)	Yes, always;	(2)
(2)	Not always;	(1)
(3)	No.	(0)

42. Are you unwavering in carrying out a plan, even if you have to overcome various obstacles and someone's resistance?

(1)	Yes, always;	(2)
(2)	Not always;	(1)
(3)	No.	(0)

43. Do you notice the appearance of fatigue even with a minimal workload or none at all?

(1)	Yes, I notice it all the time;	(2)
(2)	I sometimes notice it;	(1)
(3)	No, I do not.	(0)

44. Do you ever want to do something bad to someone and do you do it?

(1)	No, I never want to and I never do;	(1)
(2)	I cannot make this statement.	(0)

45. Do you show great patience and self-control in situations which irritate you?

(1)	Yes, always;	(2)
(2)	Not always;	(1)
(3)	No.	(0)

46. If someone disagrees with you, do you try to convince that person that you are right? Or do you consider it unnecessary to convince the other and go ahead in the way you find necessary (even if you must use force)?

(1)	I do not consider persuasion necessary;	(2)
(2)	It is rare, but there are cases where I use force, not persuasion;	(1)
(3)	The other person must be convinced first.	(0)

47. Are all your habits good and desirable?

(1)	Yes;	(1)
(2)	No.	(0)

48. Can you neglect the rules of personal safety and take risks from a desire to test your boldness?

(1)	Yes, I can;	(2)
(2)	Possibly;	(1)
(3)	No, I will not do this.	(0)

49. Do you think that your sense of personal dignity suffers if you permit yourself even the slightest deception or unworthy act?

(1) Yes, of course; (2)
(2) Sometimes for practical reasons one may act this way, and the sense of personal dignity should not suffer; (1)
(3) No, I do not think so. (0)

50. Do you think that the work assigned to you must be done well and on time?

(1) Yes, unquestionably; (2)
(2) It depends on what kind of work it is; (1)
(3) No, I do not. (0)

51. Have you had arguments with friends or relatives because you did not want to do something against your conviction?

(1) Yes, I have; (2)
(2) I can remember such a case; (1)
(3) No. (0)

52. Do you ever gossip?

(1) No, never; (1)
(2) I cannot say categorically that I never do. (0)

53. Can you compensate for a decline in work capability by greater effort of will?

(1) Yes, I am always able to do so; (0)
(2) Sometimes I can; (1)
(3) I can only compensate slightly for a decline in work capability by greater exertion of will. (2)

54. Do you feel a constant need to oversee someone, to give advice and material aid?

(1) As long as I can remember I have been concerned about someone; (2)
(2) There was once such a case; (1)
(3) No. (0)

55. Do you like to talk about your achievements?

(1) Yes, an achievement is a fact and there is no need to be embarrassed to talk about it; (0)
(2) Sometimes; (1)
(3) No, I do not like to. (2)

56. Do you think that anyone considers personal interests to be closer than public interests and people will not do things that will cause them inconvenience and worry?

(1) Yes, I think so; (0)
(2) There are sometimes cases where one must give up one's own personal interest and peace of mind. (1)
(3) No, I do not. All our actions should be subordinate to public, not personal interests. (2)

57. What is your attitude toward persons employed in yard clean-up, garbage collection, junk dealing, and sewage disposal? Could you under certain circumstances work in these jobs or do you consider them unworthy?

(1)	I believe that a person should aspire to more worthy occupations and I personally would never work cleaning yards, collecting garbage, and so on;	(2)
(2)	Possibly I could if there were no choice;	(1)
(3)	These are occupations like any other. If it were necessary, I could become a garbage collector or junk dealer.	(0)

58. Are you completely free of any superstitions? Do you believe in omens?

(1)	I do not believe in any superstitions or omens;	(1)
(2)	I cannot say that I am completely free of all superstitions.	(0)

59. Do you have a clear major goal in life for which you would endure temporary inconveniences and deprivations?

(1)	Yes, I do have such a goal;	(2)
(2)	It depends on the inconveniences and deprivations;	(1)
(3)	No, I would not put up with inconvenience and deprivation.	(0)

60. If you saw a new kind of device at a fair, in a store, in the movies, or on television, would you definitely be interested in how it works and where it can be used?

(1)	Yes, of course;	(2)
(2)	Possibly;	(1)
(3)	No, I am not curious.	(0)

61. If you have undertaken a task, do you have doubts about your success? Are you confident that you will handle it?

(1)	Yes, I always believe that I can handle it;	(2)
(2)	Sometimes I'm not confident;	(1)
(3)	I am not confident of success until I have done it.	(0)

62. Do you believe that labor is strictly necessary to a person, even if it demands great physical or mental exertion?

(1)	Yes, of course;	(2)
(2)	Possibly;	(1)
(3)	One must choose work that does not require great expenditures of effort and energy, and if possible it is better not to work at all.	(0)

63. Do you always censure a person who has committed an amoral act?

(1)	Yes, always;	(2)
(2)	It depends on the circumstances;	(1)
(3)	No, I do not.	(0)

64. Do you think that the collective is a great force that can handle any task?
   (1) Yes, of course; (2)
   (2) Sometimes; (1)
   (3) No, I do not. (0)

65. Why did you choose your present job?
   (1) Good pay; (2)
   (2) It is the most convenient temporary means to prepare for getting another, preferred job; (1)
   (3) It matches your interest and inclination; (2)
   (4) It is a profession of the future; (1)
   (5) It is the profession of your parents. (2)

66. Do you want to know as much as possible about your occupation, the best way to master it, and how to raise your qualifications?
   (1) Yes, I am always working to improve my qualifications and expand my specialized knowledge; (1)
   (2) Sometimes one must expand one's knowledge of the occupation; (1)
   (3) No, I do not think that I need to know more about my occupation. (0)

67. Do you ever brag?
   (1) No, never; (1)
   (2) On occasion. (0)

68. What is your work experience?
   (1) Less than 10 years of work experience; (1)
   (2) More than 10 years of work experience; (2)
   (3) Less than three years in the present occupation; (1)
   (4) More than three years in the present occupation; (2)
   (5) You have mastered one occupation; (1)
   (6) You have mastered several occupations. (2)

69. Have you had rich experience of life?
   (1) You have not had to change your geographic place of residence frequently; (1)
   (2) You have had to change your geographic place of residence numerous times; (2)
   (3) You have not encountered special difficulties in life because you have always had strong guidance (parents and relatives); (1)
   (4) You have had to achieve everything in life through your own efforts because you did not have strong guidance; (2)
   (5) You have never been abroad; (0)
   (6) You have been abroad. (1)

70. Your interests and knowledge center mainly around your specialization, or:

(1)	You have a good knowledge of Russian literature and the classic Russian writers;	(1)
(2)	You have a poor knowledge of Russian literature;	(3)
(3)	You have a good knowledge of contemporary Soviet literature;	(1)
(4)	You have a poor knowledge of contemporary Soviet literature;	(0)
(5)	You have a good knowledge of classic and contemporary foreign literature;	(1)
(6)	You have a poor knowledge of classic and contemporary literature.	(0)

71. Do you ever lie?

(1)	Never;	(1)
(2)	I cannot say I never lie.	(0)

72. Are you satisfied with what you have achieved in life or do you consider yourself a failure?

(1)	Absolutely unsatisfied;	(0)
(2)	Partially satisfied;	(1)
(3)	Satisfied.	(2)

73. Are you confident that when it is hard for you in the production collective you will receive help?

(1)	Yes, of course;	(2)
(2)	Possibly;	(1)
(3)	No, I am not confident at all.	(0)

74. Are you satisfied with your work position and prospects for growth at your production site?

(1)	Yes;	(2)
(2)	Not completely;	(1)
(3)	No, I am completely dissatisfied.	(0)

75. Are you satisfied with your living conditions?

(1)	Yes;	(2)
(2)	Not completely;	(1)
(3)	No.	(0)

76. Do you observe in yourself a decline of interest in work and an inconsistent attitude?

(1)	Yes, very often;	(2)
(2)	Sometimes;	(1)
(3)	No.	(0)

77. Do you suffer from sleeplessness? Are you sometimes helplessly sleepy during the day?
 (1) Yes, I often note this; (2)
 (2) Seldom; (1)
 (3) No, never. (0)

78. Do you always act honestly in all things?
 (1) Yes, of course, always and in all things; (1)
 (2) No. (0)

79. When you are in a difficult situation, do you try various steps to come out of it successfully? Do you search vigorously for a way out of the difficulties?
 (1) Yes, always; (2)
 (2) I try, but not always successfully; (1)
 (3) No, I wait until everything is over. (0)

80. Do you like to purchase reserve supplies (food, work materials, and the like)?
 (1) Yes, very much; (2)
 (2) I sometimes do; (1)
 (3) No, as a rule I do not. (0)

81. Do you always insist that people around you (at home and at work) and you yourself carry out promises?
 (1) Yes, always; (2)
 (2) Not always; (1)
 (3) No, I do not. (0)

82. If you are doing something, do you try to do only the basic job or do you try to call attention to every little point, go into detail, and do the job not only well but elegantly?
 (1) Yes, I always go down to fine points and carry every little thing through to completion; (2)
 (2) Not always; (1)
 (3) If it is not necessary to go down to fine points, I do just the basic job and do not pay attention to the rest. (0)

83. Do you think that labor discipline cannot be violated in any case?
 (1) Yes, of course; (2)
 (2) It depends on circumstances; (1)
 (3) No, I do not think so. (0)

84. If you have decided to do something, do you carry it through with vigor and determination?
 (1) Yes, if I have already decided I am confident of success and act with determination; (2)
 (2) Not always with determination; (1)
 (3) No, I do not act with determination; I have doubts about success and wonder if I should drop the matter. (0)

85. How do you behave in an argument? Do you get mad or do you try to prove your point calmly?

(1)	I never get mad, but calmly prove my point of view;	(2)
(2)	Sometimes I get mad;	(1)
(3)	I lack self-control in an argument and always get mad;	(0)

86. Do you resort to forceful means when you have to prove your rights to something?

(1)	Yes, fairly often;	(2)
(2)	It has happened, but rarely;	(1)
(3)	No, I try to convince people with words.	(0)

87. Do you enjoy types of entertainment where you can show off your daring?

(1)	Yes, very much;	(2)
(2)	Sometimes;	(1)
(3)	No, I do not.	(0)

88. If friends or acquaintances ask you to do something and you understand that it is not exactly a proper, honest thing to do, what do you do?

(1)	I never do anything that offends my sense of dignity and honor;	(2)
(2)	It depends on the circumstances;	(1)
(3)	I will sacrifice my honor for a friend.	(0)

89. If you do anything, do you always do it conscientiously?

(1)	Yes, always and in everything;	(2)
(2)	Sometimes I do work improperly and it bothers me;	(1)
(3)	If I know that no one will check and no one will be harmed by it, I do things "any old way."	(0)

90. Do you express your convictions and defend them among your friends or at a meeting if they do not agree with the opinions of others?

(1)	Yes, I always state my opinion and defend it vigorously;	(2)
(2)	Sometimes I express it, but not always;	(1)
(3)	If my opinion or conviction does not agree with the opinion of the majority, I am better off to keep quiet.	(0)

91. Are you always ready to help someone who needs outside help?

(1)	Yes, of course;	(2)
(2)	Yes, if it is a good acquaintance or friend;	(1)
(3)	If it does not hurt me.	(0)

92. Do you like to stand out in a group at work by your behavior, clothing, or statements?

(1)	Yes, of course.	(0)
(2)	Sometimes;	(1)
(3)	No, I do not like to attract attention for any reason.	(2)

93. Are you ready if necessary to undergo inconveniences and infringement on your own interest, to suffer material loss for the sake of other people.

(1)	If a person is in trouble, I will always help, even if it is not entirely in my advantage;	(2)
(2)	Only if I am absolutely convinced that my help is absolutely necessary;	(1)
(3)	If the person is not a friend or someone close to me I will not help if it would bring unpleasantness for me.	(0)

94. Do you believe that a person absolutely ought to strive for a position of honor in any chosen occupation?

(1)	Yes, of course;	(2)
(2)	It is desirable but not obligatory;	(1)
(3)	No, I do not. If I am satisfied with the material situation I will never strive to attain a leadership position.	(0)

95. If you are undertaking to do something do you always consider how this will relate to the basic goal which you have set for yourself in this period of your life?

(1)	Yes, if something may hinder the main goal I will reject it;	(2)
(2)	Sometimes I do not consider this;	(1)
(3)	I do not have such a main goal. In each case I do as I think necessary.	(0)

96. Are you interested in the problems and advances of various areas of the economy, science, art, and technology which are not related to your specialization?

(1)	Yes, I always take a lively interest and know a great deal about them;	(2)
(2)	Sometimes I am interested to read or hear about them, but I do not do this systematically;	(1)
(3)	No, I'm only interested in my own field.	(0)

97. Do you believe that life is all right and that even if unpleasant situations occasionally arise, everything will work out and be fine again?

(1)	Yes, I am confident of this;	(2)
(2)	No, sometimes I doubt this;	(1)
(3)	No, there is more bad than good in life and this constantly spoils my mood.	(0)

98. Are you familiar with the uplifting feeling that comes from a consciousness that your labor was useful to society.

(1)	Yes, I know that my labor is essential to society, I love to work, and I often experience this uplifting feeling;	(2)
(2)	Sometimes I feel moral satisfaction from my labor, but not always;	(1)
(3)	No, I consider my labor a heavy and unfair burden and receive no special pleasure from it.	(0)

99. Do you think that a person who constantly violates ethical norms and rules of social behavior deserves not only censure but also strict punishment.

(1)	Yes, absolutely;	(2)
(2)	Sometimes;	(1)
(3)	No, I do not think so. It is a personal matter.	(0)

100. Is it easy for you take up all the good initiatives that come from the collective of persons around you (at work and at home)?

(1)	Yes, I am always ready to take up a good iniative and love to work and relax in the collective;	(2)
(2)	Not always;	(1)
(3)	I do not like collective initiatives; I like to work and relax alone.	(0)

101. In choosing your present job which of the following attracted you?

(1)	Prospects of rapid growth;	(2)
(2)	Good organization of labor;	(2)
(3)	Glamor;	(1)
(4)	Work with interesting people;	(1)
(5)	______________	(1)
(6)	______________ (write in factors which guided you in coming to work if they are not included in a list above).	(1)

102. Do your professional interests concern you in nonworking time also (do you think about work, read specialized literature, attend lectures, and the like)?

(1)	Yes, all the time;	(2)
(2)	Sometimes;	(1)
(3)	No, at home I shut myself off completely from work interests.	(0)

103. In what stage of mastering the highest skills of your occupation do you find yourself?

(1)	You have the lowest rating;	(0)
(2)	You have an average rating;	(1)
(3)	You have the highest rating.	(2)

104. Have you had great upheavals in your life (death of people close to you, serious family and work conflicts, natural disasters, and the like)?

(1) Yes, many of them; (2)
(2) One or two cases; (1)
(3) No, there have been no serious upheavals. (0)

105. Your interests and knowledge for the most part center only on your occupation, or:

(1) You love and are knowledgeable about the music of the Russian composers and often go to the opera and symphony; (1)
(2) You are not very familiar with the music of the Russian composers; (0)
(3) You are very familiar with foreign classical music; (1)
(4) You do not know foreign classical music; (0)
(5) You are knowledgeable about contemporary Soviet and foreign music; (1)
(6) You are not very familiar with contemporary Soviet and foreign music. (0)

106. Are you satisfied with your character?

(1) Yes, completely; (2)
(2) Not entirely; (1)
(3) No, I am very dissatisfied. (0)

107. Do you like your production collective?

(1) Yes, there are very good people in our collective; (2)
(2) Not entirely; (1)
(3) No, we have a bad collective. (0)

108. Do you think that your job will be able to satisfy all your material and living needs quickly and well?

(1) Yes, I think that it will; (2)
(2) Possibly, but I'm not sure; (1)
(3) No, I do not. (0)

109. Does your material situation enable you to organize your everyday life in conformity with your desires, taste, and needs?

(1) Generally, yes; (2)
(2) Not entirely; (1)
(3) No. (0)

110. Is it hard for you to get to sleep and stay asleep? Are you sometimes sleepy during the day?

(1) Yes, I notice this all the time; (2)
(2) Sometimes; (1)
(3) No, I do not notice this. (0)

111. Do you notice that you are often in a state of great irritation or depression?

(1)	Yes, I often notice this;	(2)
(2)	This sometimes happens with me;	(1)
(3)	No, I do not.	(0)

112. Are you a disciplined person?

(1)	Yes, I never violate discipline and working order;	(1)
(2)	No, I cannot say that about myself.	(0)

Scoring and Decoding the Questionnaire Data

After the subject has answered all the questions the experimenter begins decoding the data from the questionnaire. On the questionnaire opposite each possible answer (in parentheses on the right) is the point value used to evaluate the particular answer. The experimentor transfers these points for each answer marked by the subject onto special Evaluation Table 2 (below); each box has a number corresponding to the number on the questionnaire blank. The point value is put in the box to the right of the question number separated by a red line. If the subject has given several answers to one question (this is possible, for example, in the answer to question No 23 about motives for selecting an occupation), the total number of points for all answers marked by the subject is written in the box with the number of the appropriate questions.

When the entire evaluation table has been filled out in this way, a set of "keys" must be used to figure the evaluation of the specific characteristics of the subject. Each key is a sheet of paper corresponding to the evaluation table in format, with a number of holes framed by different colors or different types of hatchuring. By placing each sheet on the evaluation table in turn, we will see the evaluations for each question related to the particular characteristic framed by one color or type of hatchuring. By adding the point values in boxes of one type we receive the general evaluation of the characteristic which is marked on the particular key (in the lower right corner) by this color or hatchuring. The maximum possible score is given on each key next to the name of the characteristic being analyzed. If the experimentor wishes, it is possible to make a quantitative evaluation by groups of characteristics, which was mentioned in the introduction to questionnaires (practical qualities, volitional qualities, moral qualities, qualities that define motives of behavior, qualities that define the attitude toward the world around, social consciousness, breadth of outlook, level of satisfaction, and existence of symptoms of fatigue).

To make the data on each test subject more objective, the questions on the questionnaire should be answered not only by the subject but also by his or her comrades at work. It is very interesting to consider the opinion of people who know the test subject well. For this reason, two special questions are included in the personal data part: 11. Who in your production collective knows you well? 12. Who in your production collective do you know well?

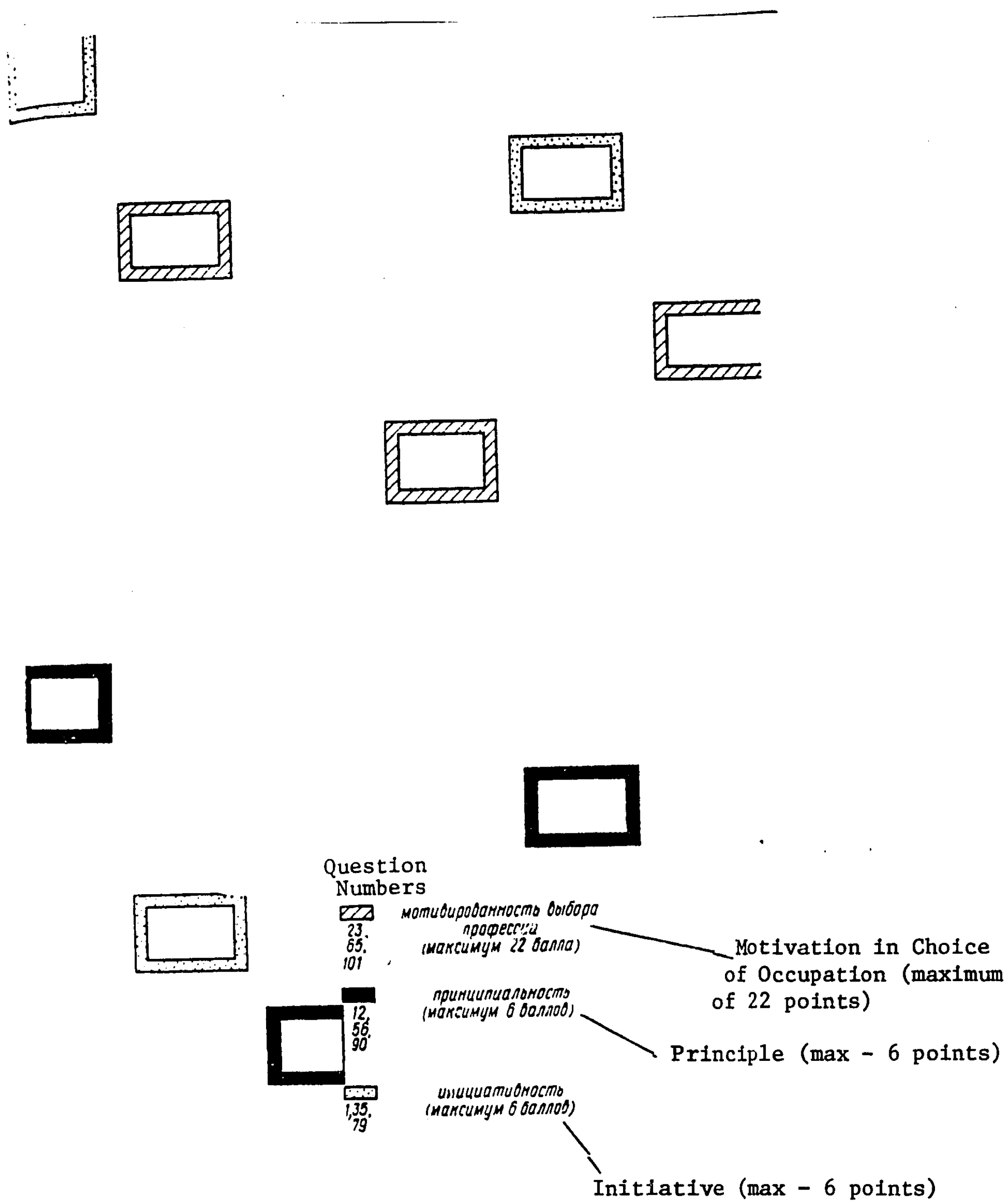
After processing the questionnaire materials we were able to form an idea of the social aspect of each operator. Then we begin studying the mental and biological

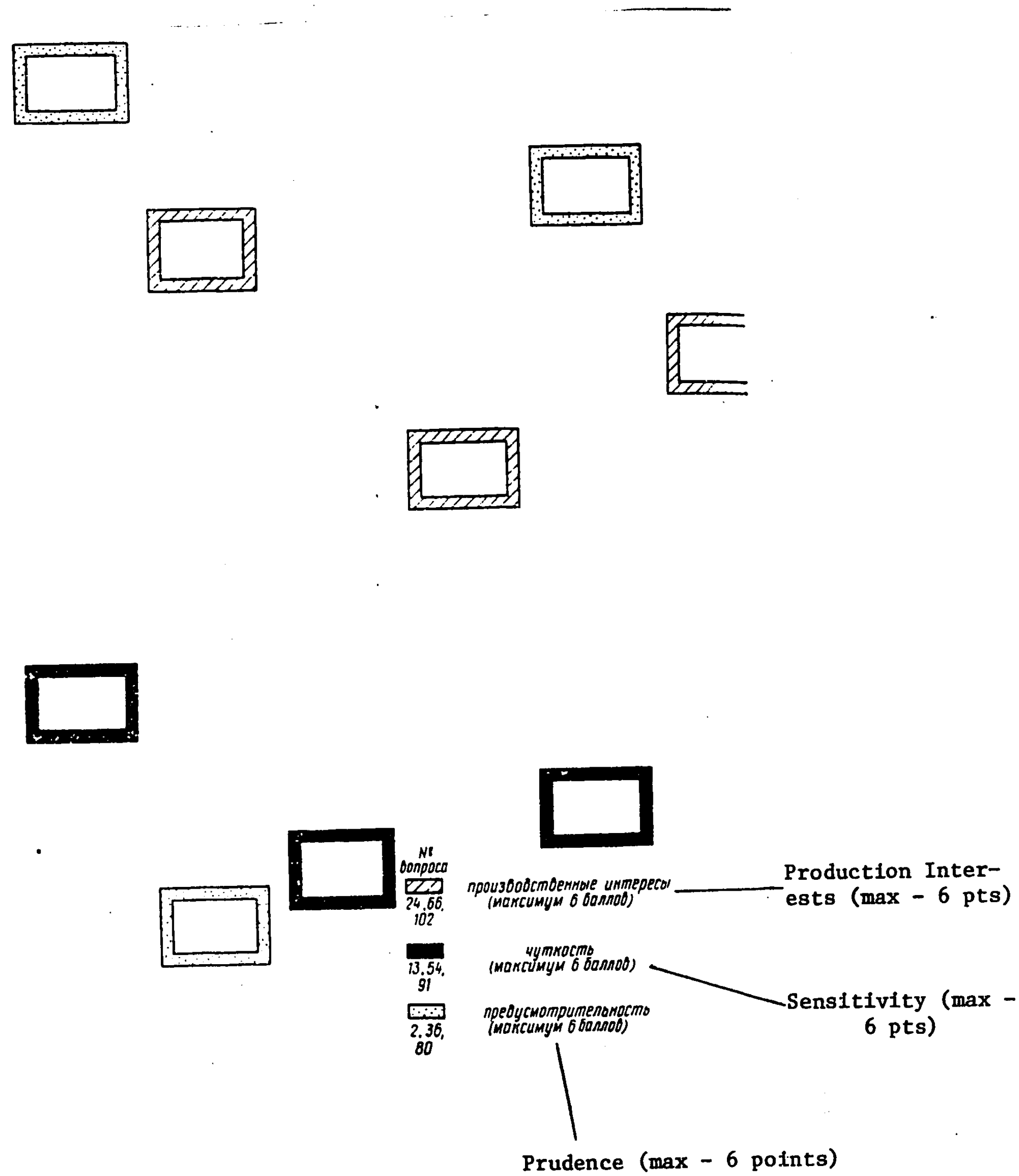
Table 2.

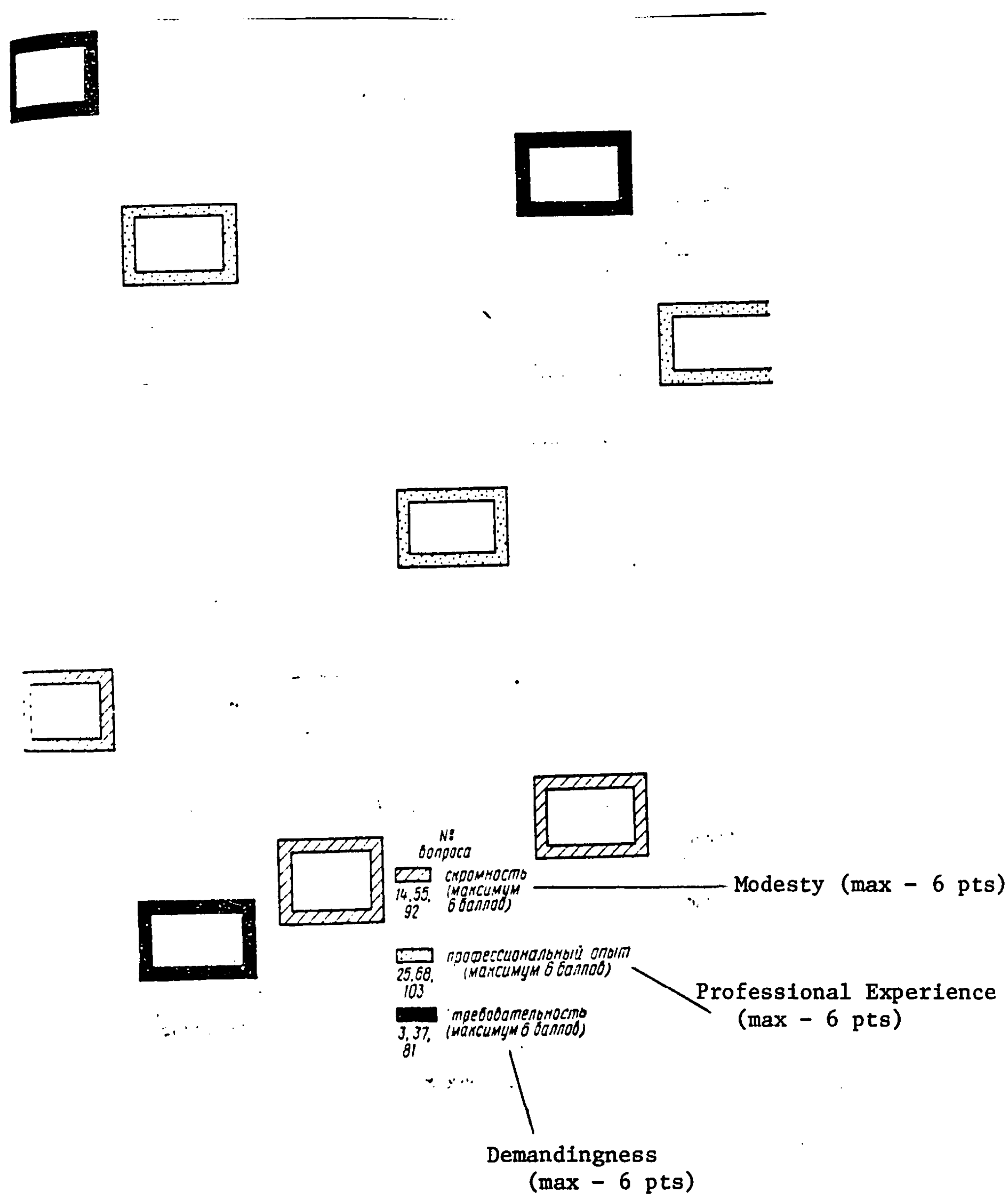
1		20		39		58		77		96	
2		21		40		59		78		97	
3		22		41		60		79		98	
4		23		42		61		80		99	
5		24		43		62		81		100	
6		25		44		63		82		101	
7		26		45		64		83		102	
8		27		46		65		84		103	
9		28		47		66		85		104	
10		29		48		67		86		105	
11		30		49		68		87		106	
12		31		50		69		88		107	
13		32		51		70		89		108	
14		33		52		71		90		109	
15		34		53		72		91		110	
16		35		54		73		92		111	
17		36		55		74		93		112	
18		37		56		75		94			
19		33		57		76		95			

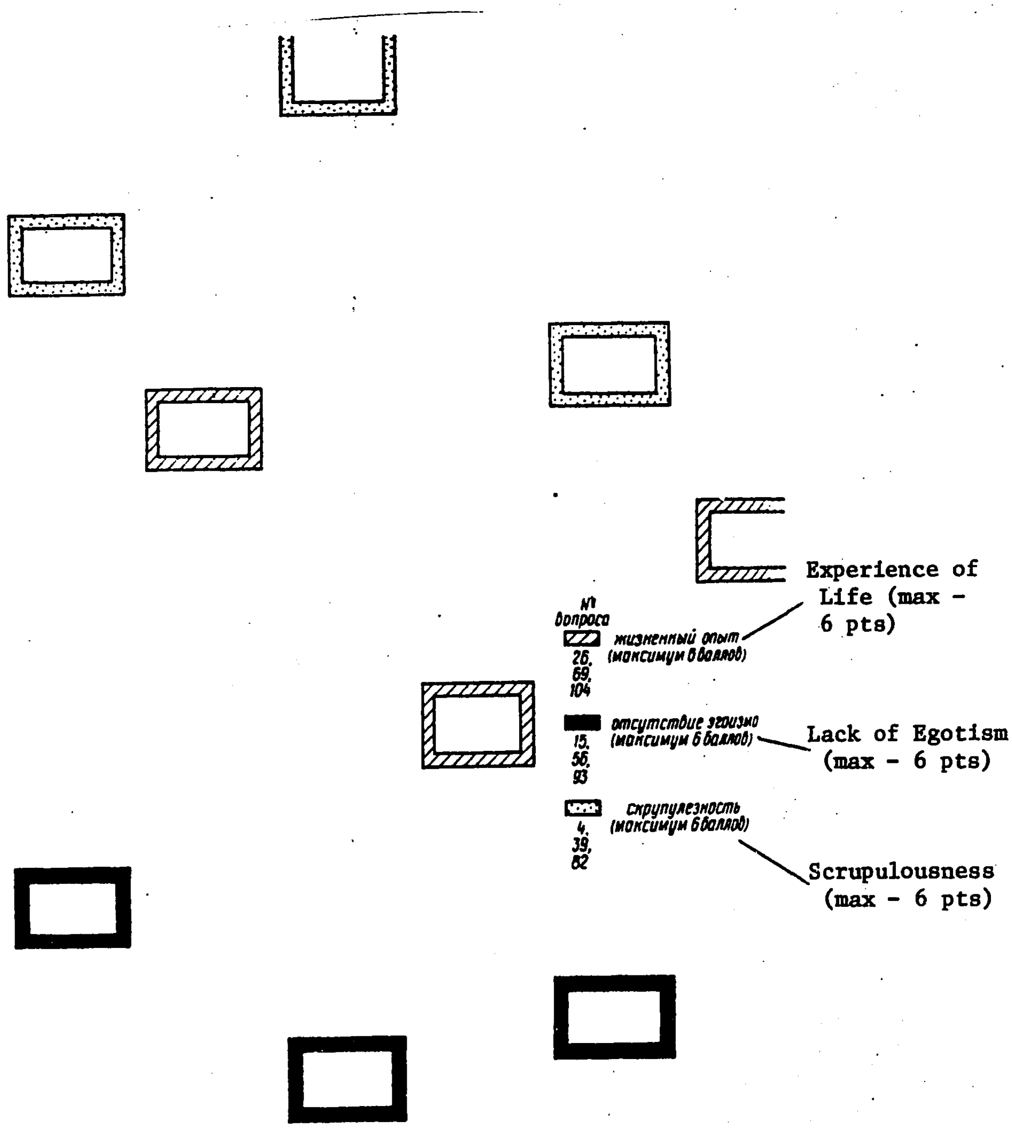
aspects, using the methodological procedures described above. Each operator was given a total of 54 evaluations (some characteristics were tested by several techniques).

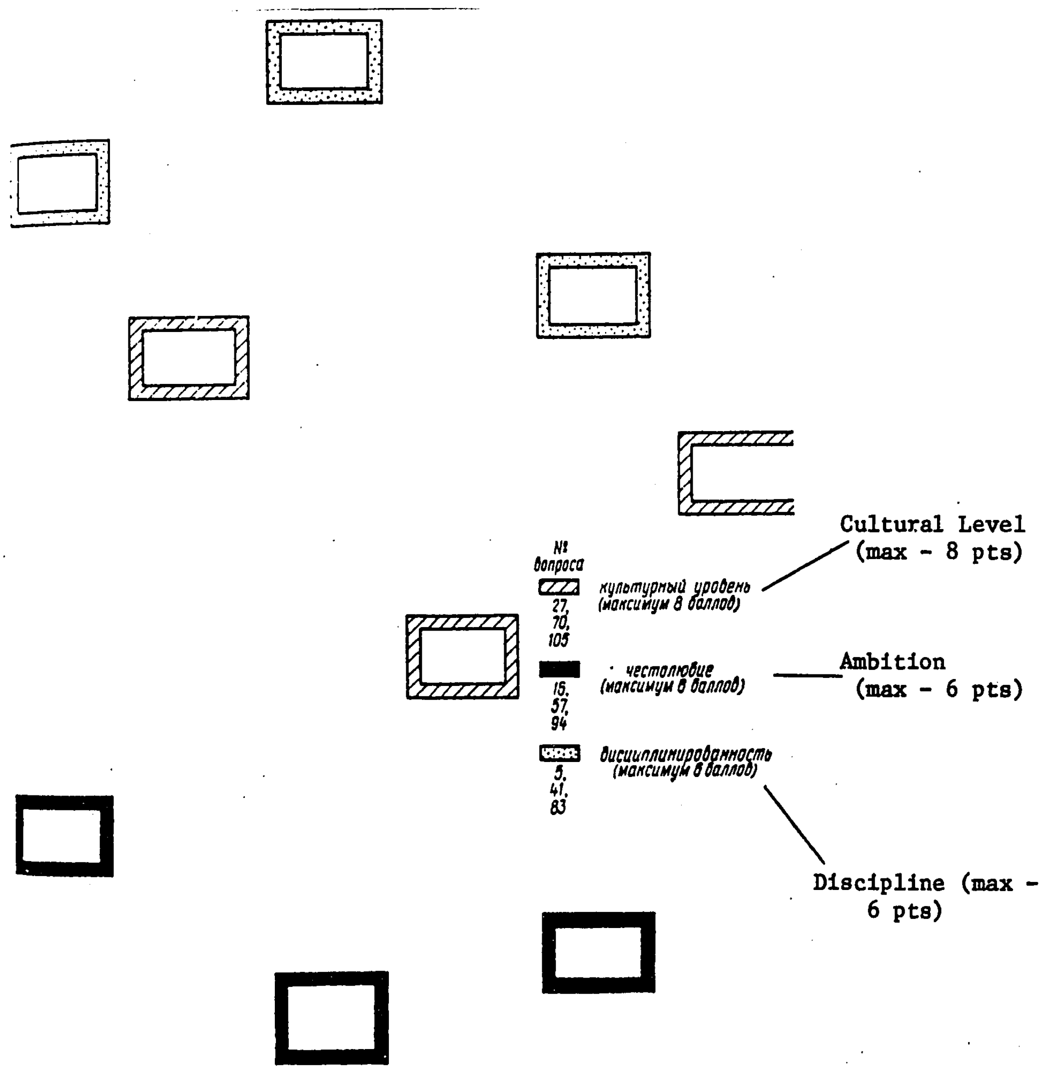
A comparison of different parameters included in the portrait of the individual operator and the reliability of the operator's work in the semiautomatic regime


Question Numbers
23, 65, 101
мотивированность выбора профессии (максимум 22 балла)
Motivation in Choice of Occupation (maximum of 22 points)
12, 56, 90
принципиальность (максимум 6 баллов)
Principle (max - 6 points)
1, 35, 79
инициативность (максимум 6 баллов)
Initiative (max - 6 points)


№ вопроса
24.66, 102
производственные интересы (максимум 6 баллов)
13.54, 91
чуткость (максимум 6 баллов)
2.36, 80
предусмотрительность (максимум 6 баллов)
Production Interests (max - 6 pts)
Sensitivity (max - 6 pts)
Prudence (max - 6 points)


№ вопроса
скромность (максимум 6 баллов)
14, 55, 92
Modesty (max - 6 pts)
профессиональный опыт (максимум 6 баллов)
25, 68, 103
Professional Experience (max - 6 pts)
требовательность (максимум 6 баллов)
3, 37, 81
Demandingness (max - 6 pts)


№ вопроса
жизненный опыт (максимум 6 баллов)
26, 69, 104
отсутствие эгоизма (максимум 6 баллов)
15, 56, 93
скрупулезность (максимум 6 баллов)
4, 39, 82
Experience of Life (max - 6 pts)
Lack of Egotism (max - 6 pts)
Scrupulousness (max - 6 pts)



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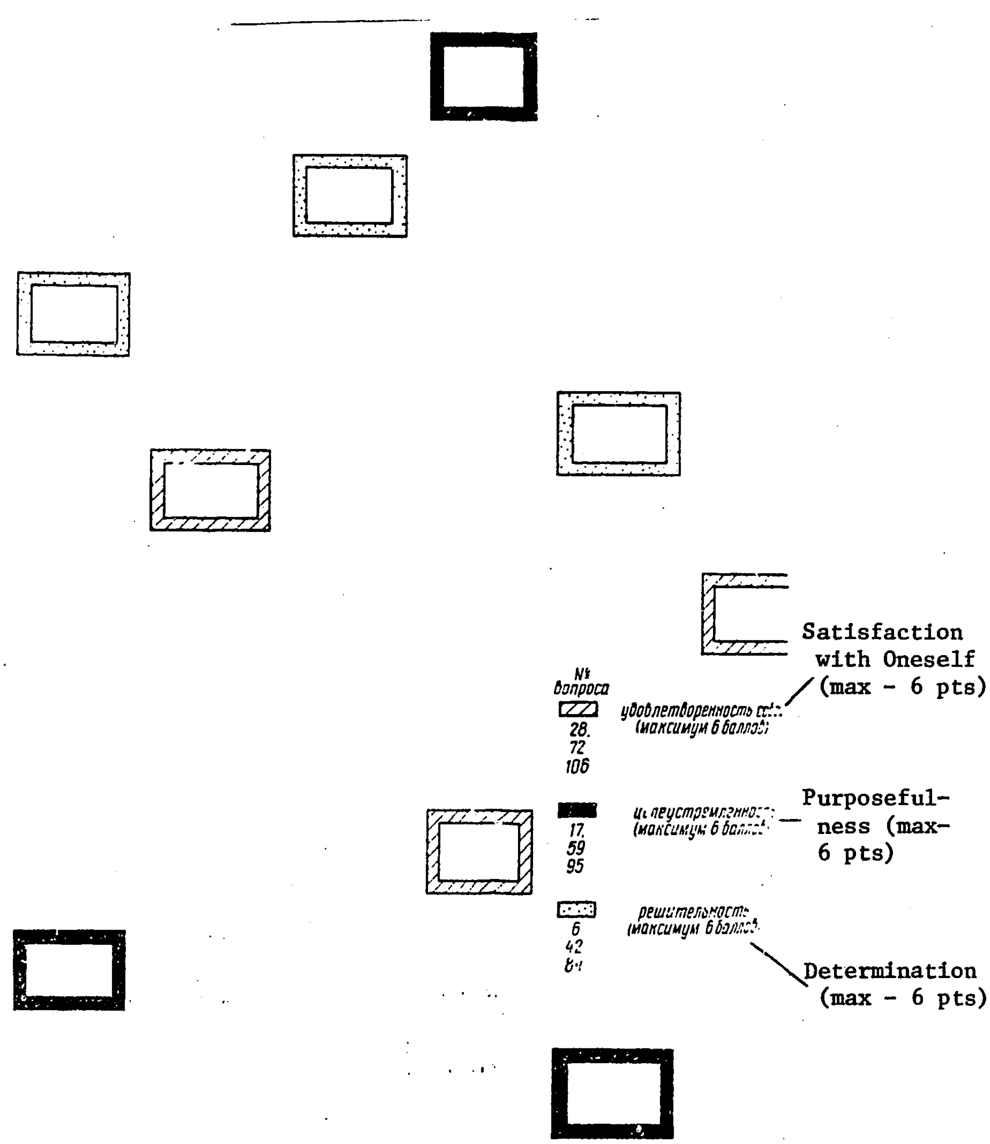
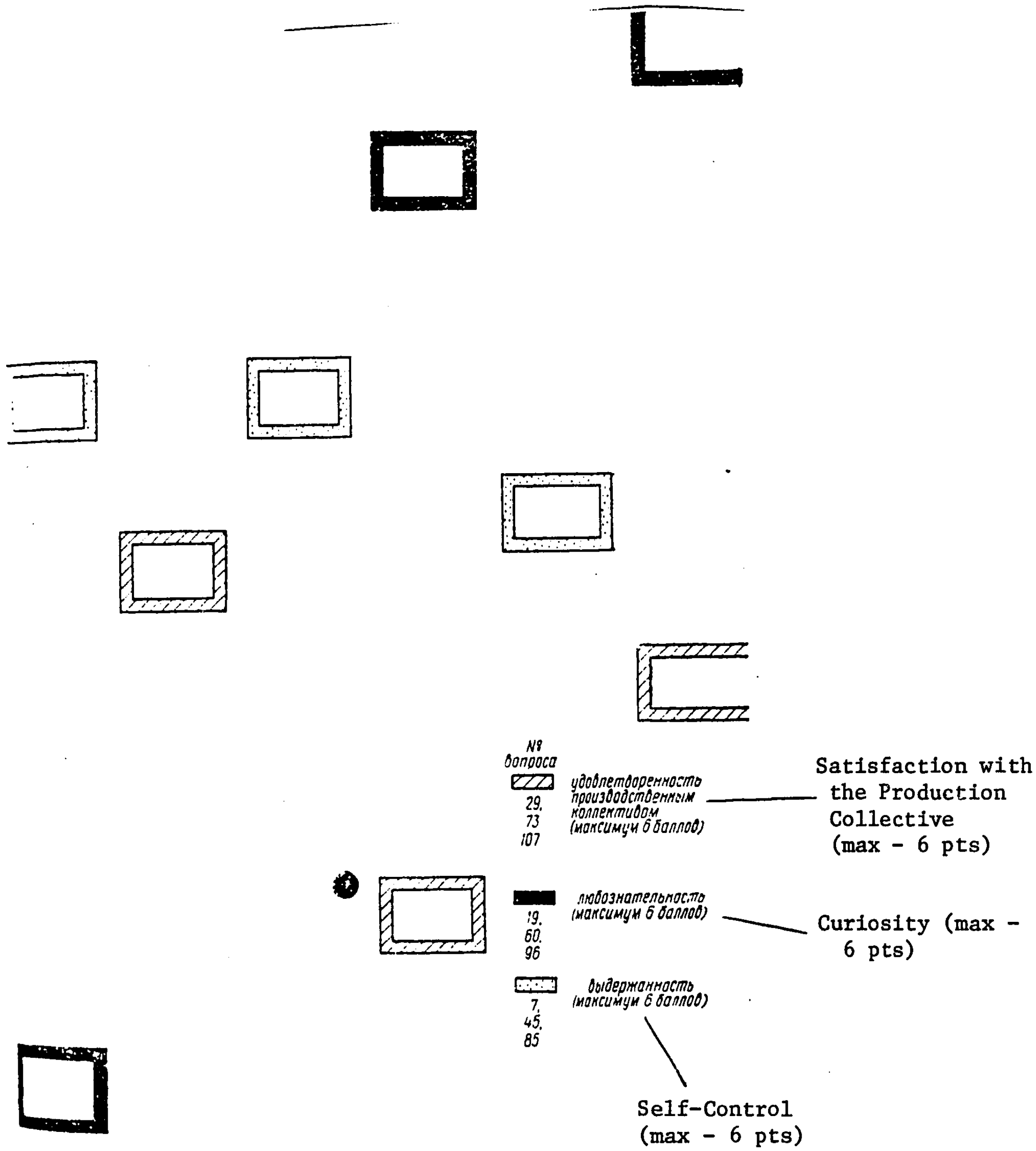
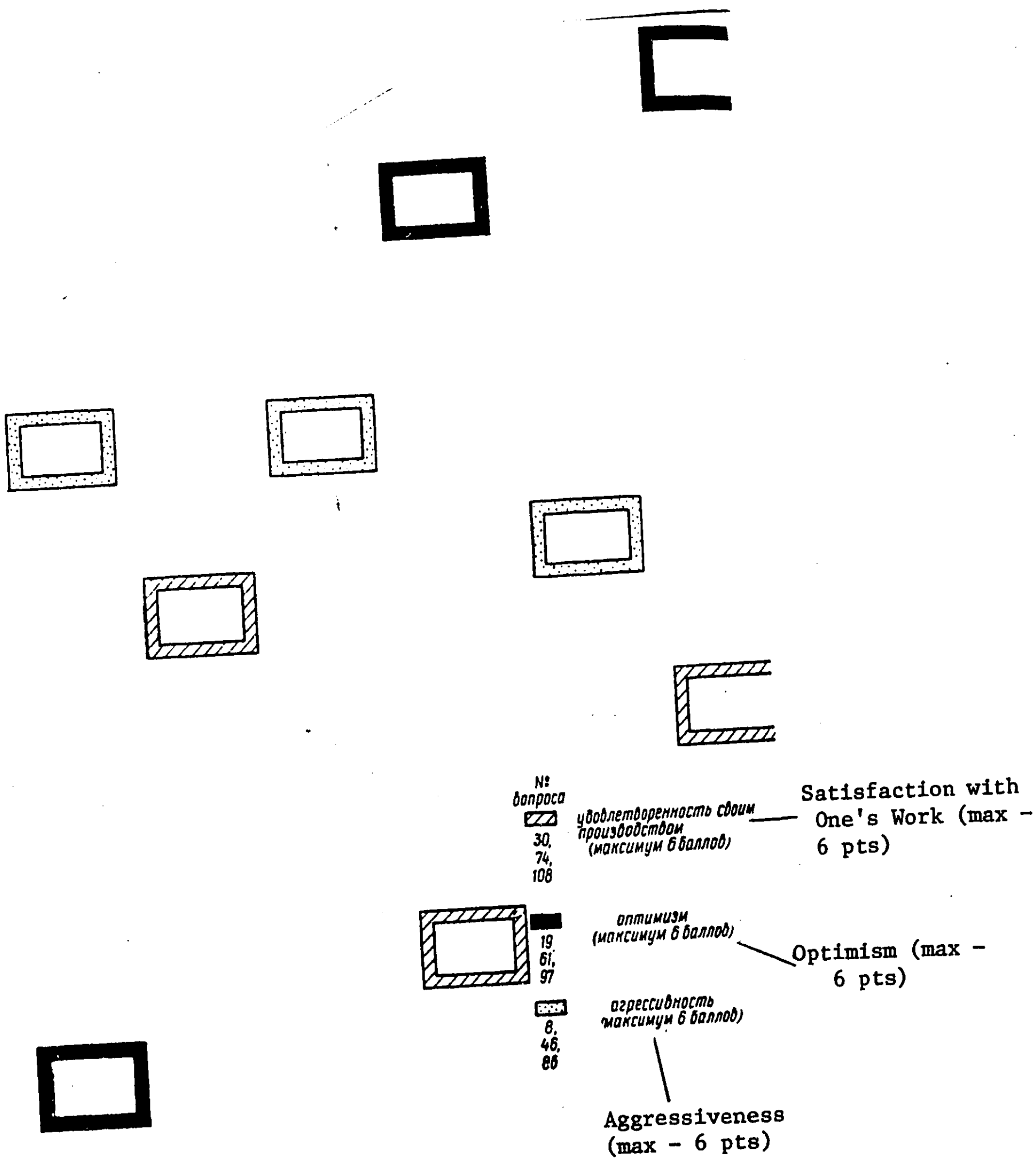
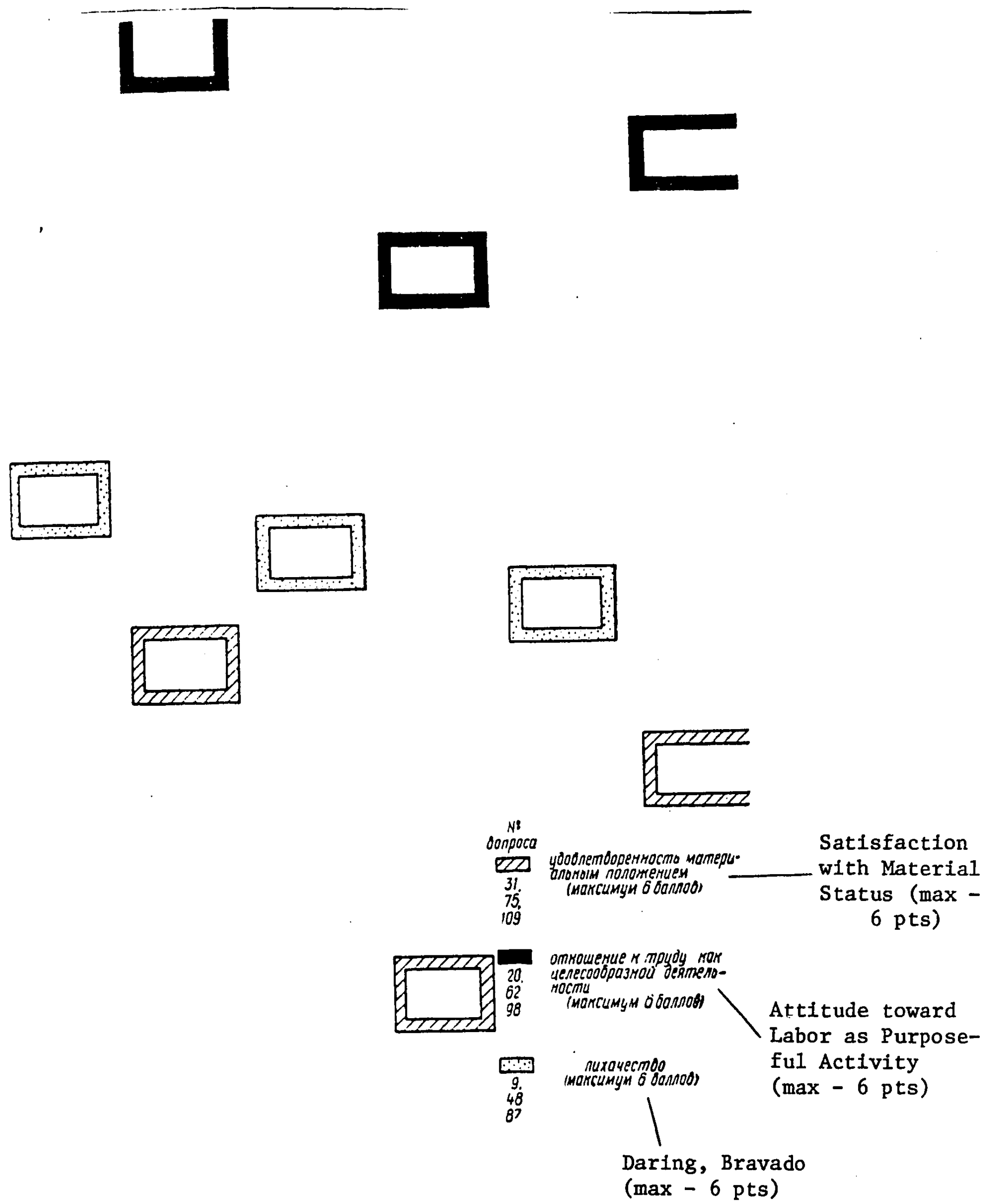

№ вопроса
28.
72
106
Satisfaction with Oneself (max - 6 pts)
17
59
95
Purposeful- ness (max- 6 pts)
6
42
Determination (max - 6 pts)


№ вопроса
удовлетворенность производственным коллективом (максимум 6 баллов)
29, 73, 107
Satisfaction with the Production Collective (max - 6 pts)
любознательность (максимум 6 баллов)
19, 60, 96
Curiosity (max - 6 pts)
выдержанность (максимум 6 баллов)
7, 45, 85
Self-Control (max - 6 pts)


№ вопроса
30, 74, 108
удовлетворенность своим производством (максимум 6 баллов)
Satisfaction with One's Work (max – 6 pts)
19, 61, 97
оптимизм (максимум 6 баллов)
Optimism (max – 6 pts)
8, 46, 86
агрессивность максимум 6 баллов)
Aggressiveness (max – 6 pts)



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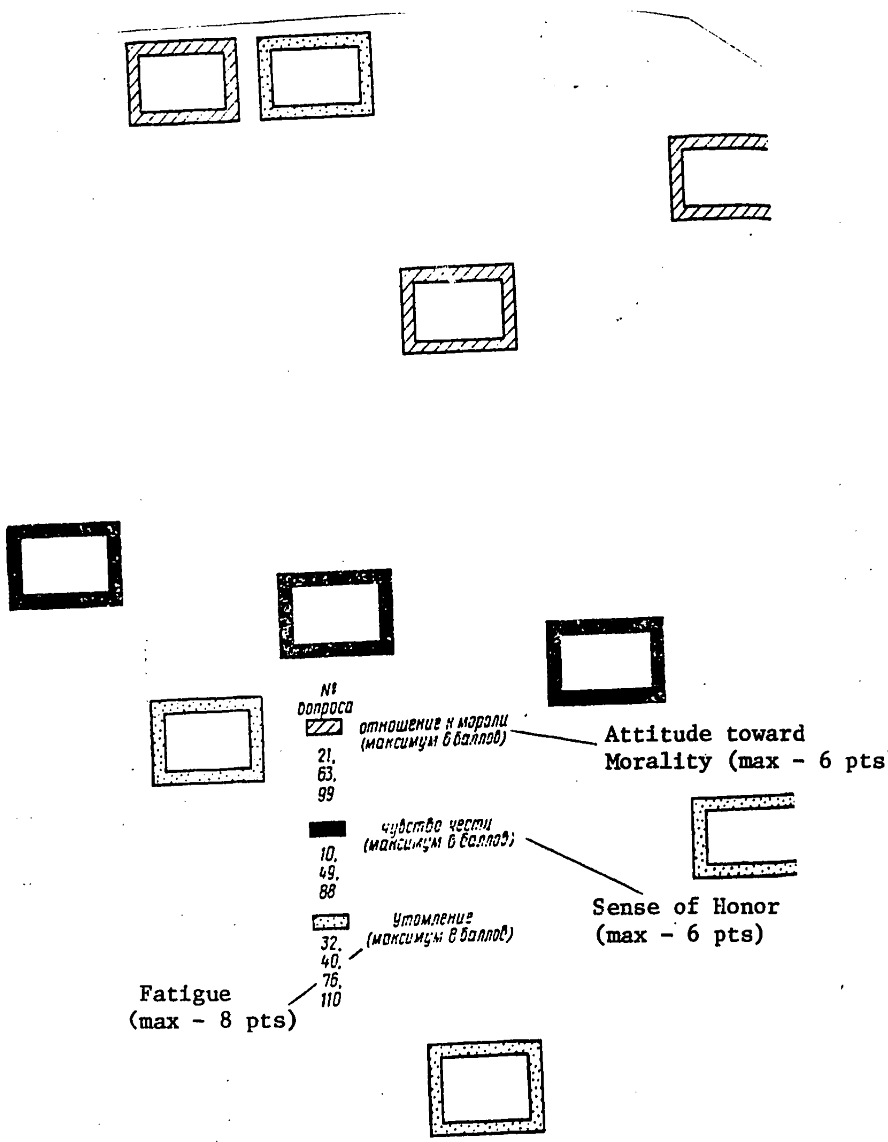
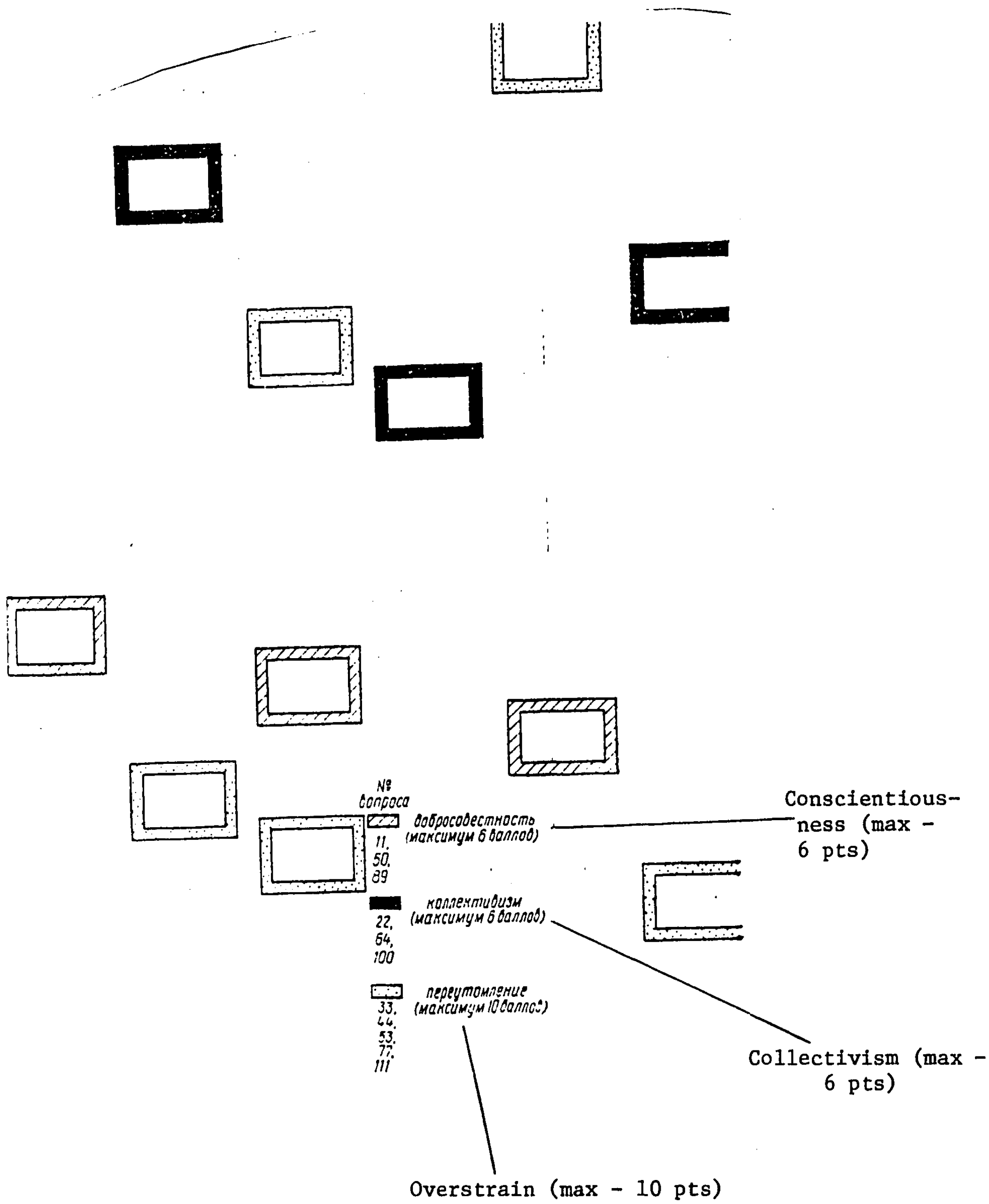
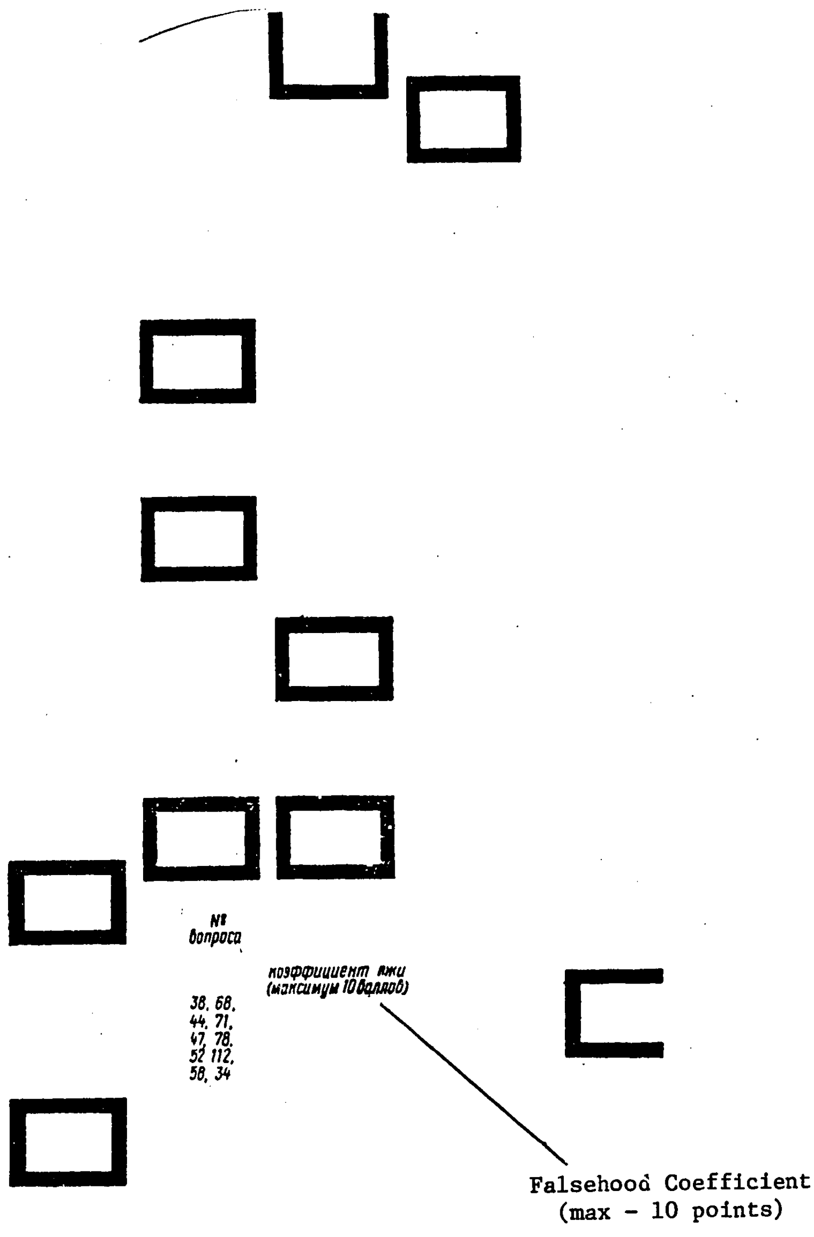

№ вопроса
отношение к морали (максимум 6 баллов)
21, 63, 99
Attitude toward Morality (max - 6 pts)
чувство чести (максимум 6 баллов)
10, 49, 88
Sense of Honor (max - 6 pts)
утомление (максимум 8 баллов)
32, 40, 76, 110
Fatigue (max - 8 pts)


№ вопроса
добросовестность (максимум 6 баллов)
11, 50, 89
коллективизм (максимум 6 баллов)
22, 64, 100
переутомление (максимум 10 баллов)
33, 44, 53, 77, 111
Conscientiousness (max - 6 pts)
Collectivism (max - 6 pts)
Overstrain (max - 10 pts)


№ вопроса
коэффициент лжи (максимум 10 баллов)
38, 68,
44, 71,
47, 78,
52 112,
58, 34
Falsehood Coefficient
(max - 10 points)

made it possible to identify those characteristics which correlate with reliability and can therefore be used as indicators to predict operator behavior in an emergency situation.

The "unreliable" operator is characterized, on the sociological plane, by lower indicators for professional interests, practical traits, and volitional qualities. Two operators who are very close to the "unreliability pole" showed marked traits of melancholy temperament.

Concerning psychological functions we may say the following. The "reliable" operator has higher indicators for attention switching and stability. The intelligence quotient according to Eyesenck approaches 120 and higher for "reliable" operators; for "unreliable" operators it is in the area of 100.

It is interesting that "unreliable" operators have a higher indicator of short-term memory than do "reliable" operators. A possible explanation is that short-term memory was studied by mechanical memorization of a meaningless series of numbers. "Reliable" operators, with a higher intelligence quotient, are probably more inclined to logical memorization than mechanical. Significant differences were also found between "reliable" and "unreliable" operators for the class of characteristics of the nervous system. "Reliable" operators have lower dynamism of the stimulation process, higher lability and mobility of nerve processes, and greater emotional stability.

It should be noted specially that in an emergency situation "unreliable" operators show signs not only of fatigue, but also overfatigue. It is apparent that the mismatch between their individual psychological characteristics and their chosen occupation have a negative effect not only on the production process, but on the state of their own health. Figure 26 below gives a profile of the "reliable" and "unreliable" operators.

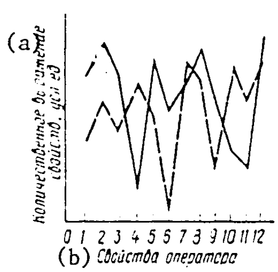


Figure 26. Profiles of the "Reliable" (——) and "Unreliable" (----) Operators

Key: (a) Quantitative Expression of Characteristics, standard units;
(b) Operator Characteristics;
(1) Professional Interests;
(2) Practical Qualities;
(3) Volitional Traits;
(4) Overfatigue;
(5) Stability of Attention;
(6) Switching Attention;
(7) Short-Term Memory;
(8) Intelligence Quotient according to Eyesenck;
(9) Quality of Switching (Mobility);
(10) Dynamism Related to Stimulation;
(11) Lability;
(12) Emotional Stability.

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Chapter 5. Modeling Operator Activity and Some Aspects of Its Practical Application.

1. Classification of Models of Operator Activity

Basic Concepts

There are dozens of definitions of such concepts as system, model, activity, and so on today. We understand that for each of these concepts it is possible to formulate another definition, which will be no better and no worse than the old one, and substantiate its usefulness. Therefore, we have chosen definitions which for certain reasons seem to us to be convenient for practical use.

A system is a set of elements that are related and interconnected, forming a definite whole, integrated unit [1].

An ergatic system is a system consisting of operators and the technical means with which they carry out their labor activity under certain conditions of a work environment.

The systems approach is consideration of the individual elements of a system with due regard for their interrelationship and mutual influence.

Ergonomic indicators are those interrelated indicators that characterize various aspects of the functioning of an ergatic system and of operator activity [2].

The operator is a person whose labor activity involves controlling an object.

Labor activity is a dynamic structure that includes a human being and converts information and energy.

Operator activity is labor activity to control an object.

Group activity is labor activity by more than one operator to control an object.

The model is a system of objects of arbitrary nature, devised for a definite purpose and homomorphically representing another system of objects.

Modeling is the study of complex phenomena by investigation of models of them.

The mathematical model is a mathematical system, formulated for a definite purpose which homomorphically represents another system of arbitrary nature.

The physical model is a system of physical objects, devised with a definite purpose, which homomorphically represents another system of physical objects.

The Systems Approach to Modeling Operator Activity

The systems approach to modeling operator activity presupposes preliminary identification of the hierarchical structure and degree of expression of the ergonomic indicators of the activity under study and then modeling these indicators with due regard for their interdependence and mutual influence.

If the operator activity under consideration can be described by a certain set A of ergonomic indicators $x \in A$, then after assigning definite weight factors to the elements of set A depending on degrees of expression it is possible to obtain ordered set B of normalized ergonomic indicators $y \in B$, which occupy a definite place in the hierarchical structure, that is

$$y_1 \prec y_2 \prec \cdots \prec y_S, \tag{5.1}$$

where S is the power of set B. Then modeling operator activity consists of representing set Y of normalized ergonomic indicators in set M of models of these indicators, that is, $f : Y \to M$.

Mathematical Models of Operator Activity

Considering the definition of mathematical model given above (5.1), mathematical modeling of operator activity consists in representing a set of normalized indicators Y in set M_M of mathematical models, that is, $f : Y \to M_M$.

Existing classifications of mathematical models of the activity of human operators (for example, the classification given in work [6]) usually begin from the principle of functionalism. The systems approach to modeling made it possible to develop a more refined classification of mathematical models of occupational activity [3]. But it does not meet the purposes of research, because it does not directly reflect the principle of homomorphism.

When classifying mathematical models of operator activity, we base our classification on the nature of the homomorphic representation of the set of ergonomic indicators. As a result, we obtain three basic classes of mathematical models of operator activity: subject-mathematical, sign-mathematical, and cybernetic (subject-mathematical in form and sign-mathematical in content). This classification is represented in Table 3 (next page).

The subject-mathematical (analog) models can be used to study any spectra of operator activity which can be described by the same mathematical relations as the phenomenon being modeled (the principle of isomorphism). The servomodels are an example of subject-mathematical models. Their essential feature is that they describe operator activity by means of transfer functions. In this case operator activity is formalized by selecting the type of transfer function according to the type of transfer function of the control object. The dynamic characteristics of

Table 3.

Class of Models	Nature of Homographic Representation	Subclass of Models	Substance of Homographic Representation	Basic Mathematical Apparatus
Subject-mathematical (analog)	Homographic representation of a physical system in mathematical systems	Servomodels	Description of operator functions by means of transfer functions	Apparatus of automatic regulation theory
Sign-mathematical	Homographic representation of a system of ergonomic indicators in mathematical systems	Logical-mathematical models	Study of neostochastic algorithms of operator activity	Algorithm theory
			Study of stochastic algorithms of operator activity	Graph theory, matrix algebra
			Stochastic model of decision-making	Probability theory
		Multidimensional statistical models	Description of professionally important operator characteristics	Factor and correlation analysis
			Forecasting occupational suitability of operators	Correlation analysis
			Forecasting efficiency of operator activity	Multidimensional statistical analysis
		Theoretical-information models	Evaluation of operator carrying capacity	Information theory
			Evaluation of essential level of automation of activity	Information theory
Cybernetic (simulation)	Homographic representation of a system of ergonomic indicators in the structure of the computer	Service models	Evaluation of the quality of operator activity	Mass service theory, Monte Carlo methods

[Table continued on next page]

[Table 3 continued]

Class	Nature of Homographic Representation	Subclass of Models	Substance of Homop graphic Representation	Basic Mathematical Apparatus
		Simulation models of group activity	Psychosocially oriented evaluation of the quality of activity of a group of operators	Algorithm theory, Monte Carlo methods
			Evaluation of the carrying capacity of a group of operators	Information theory, Monte Carlo methods

the operator transfer functions are synthesized by the techniques of automatic regulation theory.

The sign-mathematical models are mathematical symbolic systems that homomorphically represent a system of ergonomic indicators. The models of psychophysiological activity based on analysis of nonstochastic algorithms [4] where ergonomic indicators are homomorphically represented in algorithmic structures (logical-mathematical models according to the classification in Table 3) are an example of the sign-mathematical models.

The cybernetic models are mathematical symbolic systems and definite computer structures that homomorphically represent a system of ergonomic indicators. The cybernetic models simulate the basic patterns of operator activity using a computer.

Regardless of the class of mathematical models, the process of mathematical modeling of operator activity can be broken down into four stages.

The first stage is study of particular aspects of operator activity (ergonomic indicators) and forming qualitative representations of the links among ergonomic indicators in mathematical terms. For example, after analysis of the psychophysiological structure of operator activity in work [5], a multifactoral mathematical model of the following type was synthesized

$$X = QZ + U, \tag{5.2}$$

where X is the matrix of original factor space, Z is the factor matrix, Q is the matrix of loads of the common factors on the signs being investigated, and U is the matrix of residual factors.

The second stage is analysis of the model using the chosen mathematical apparatus and computer technology. This produces the output data (values of ergonomic indicators). In the examples cited the mathematical apparatus is multidimensional statistical analysis, and a computer is used for computation.

The third stage is evaluating the adequacy of the model, that is, evaluating the degree of correspondence between the results of operator activity and the theoretical consequences of the model.

The fourth stage is subsequent analysis and updating of the model, because in the process of the development of ergonomics new findings on ergonomic indicators accumulate and there comes a time when in light of these findings the originally proposed mathematical model is outdated.

Physical Models of Operator Activity

Considering the definition of a physical model (5.1), physical modeling of operator activity involves representing the set of normalized ergonomic indicators Y in set M_ϕ of models of arbitrary physical nature, that is, $f : Y \to M_\phi$.

Physical modeling of operator activity is based on the physical resemblance of ergonomic indicators and the model, that is, at similar moments in time the values of the ergonomic indicators should be adequate to their values for the model. The existence of adequacy makes it possible to compare experimental data obtained for the model with real operator activity.

The work of an operator on a simulation trainer that models the dynamics of the controlled object is an example of physical modeling of operator activity. This means that each element of information model $a \in A$ can be mutually and uniquely matched with an element of the real equipment $b \in B$; each operation F_a of a certain class of operations which transforms element $a_1 \in A$ into $a_2 \in A$, $F_a(a_1) = a_2$, can be mutually and uniquely matched with operation F_b, which transforms element $b_1 \in B$ into $b_2 \in B$, $F_b(b_1) = b_2$, that is $F_a \to F_b$. In other words, operator activity on the trainer is a reflection of the structure of the real activity.

2. Synthesizing Mathematical Models of Operator Activity

Analysis of Mathematical Models of Operator Activity from the Point of View of Practical Application

Considering the classes of mathematical models of operator activity proposed (see Table 3 above), we can state that from the standpoint of practical application the analog models have the greatest limitation.

Because ergonomic indicators depend on many factors, "creation of an adequate mathematical model of operator activity using the apparatus of automatic regulation theory is a very complex problem" [7]. Therefore, the usual procedure is to devise mathematical models that consider some one characteristic of the human operator that predominates in a particular type of activity. This makes it necessary to formulate a new transfer function in each particular case and to test the adequacy of the model under conditions of the very rigid constraints imposed on ergonomic indicators.

Sign-mathematical models of operator activity have received the widest application at the present time. Their indisputable advantage is formalization, which makes it possible to represent particular components of activity and relationships among them in the form of symbols. This makes it possible to manipulate them in conformity with rules established by such formal sciences as logic and mathematics. Work [7] describes certain multidimensional statistical models and nontrivial ways to apply them in practice.

In our opinion, simulation modeling of operator activity is most promising. This is because human behavior is distinguished by great complexity and is described by a system of ergonomic indicators, only some of which can be formalized without serious limitations. In these cases simulation modeling makes it possible to obtain quantitative values of ergonomic indicators with adequate computer memory and available machine time.

It should be noted that logical-mathematical models of operator activity, in particular algorithmic models, are often an essential attribute of simulation modeling.

Simulation Psychological Model of Operator Activity

The construction of a simulation model of group activity is based on the principles set forth in works [8, 9]. The model simulates the activity of two operators interacting in the process of running a technical system, as well as the work of this system. An essential condition for modeling is the availability of a known sequence of actions by both operators, that is, an algorithm of operator activity. Thus, the algorithmic model obtained by analyzing the algorithm of operator activity is a constituent part of the simulation model.

The algorithm of operator activity was constructed by the methodology of G. M. Zarakovskiy [4]. But the special features of simulation modeling necessitated a certain modernization of the graphic representation of the algorithms.

In constructing the algorithm of operator activity a word algorithm (presented in operating instructions) that describes the functioning of the ergatic system is taken as the basis. The algorithm being analyzed is usually represented in tabular form where the operations (actions, instructions, and the like) carried out concurrently are written on one line. The table also notes fixed moments in time before which the operator does not have the right to begin work.

After further analysis the algorithm is broken down into line-subtasks, each of which belongs to one of the following types:

1. joint, if operations performed by several operators are written on one line of the table;

2. machine, if only equipment work is written on the given line;

3. individual, if operations performed by one operator are written on the given line.

For each subtask the degree of importance is established, that is, an evaluation is made of the impact of successful performance of the given subtask on successful execution of the entire algorithm.

A line entry of the algorithm of operator activity is written, for example:

$$E_1^V \overset{1}{\downarrow} D_{3,1}^V I_2^V \overset{1}{\uparrow} I_4^N D_{5,2}^V, \tag{5.3}$$

where E, D, and I are machine, individual, and joint subtasks respectively; V is the index of significant subtask; N is the index of insignificant subtask; E_1, I_2, and I_4 are subtasks 1, 2, and 4 respectively; $D_{3,1}$ is subtask 3 performed by by operator 1; $D_{5,2}$ is subtask 5 performed by operator 2; and the arrows ↑↓ indicate the further order of performance of subtasks if the subtask preceding the arrow pointing upward has not been performed.

The construction of algorithms of operator activity is an important stage of modeling, because the final efficiency of the investigation depends on constructing the algorithm correctly (an over-detailed algorithm leads to an unjustified increase in the volume of work and machine time, while an over-simplified algorithm reduces the precision and reliability of results).

The line entry of the algorithm of operator activity (5.3) is not sufficiently graphic, which makes it difficult to use it during analysis. Therefore, it is useful to represent the algorithm in graphic form. Figure 27 below gives an example of writing an algorithm of operator activity. The diagram represents the work of just one operator performing monitoring and control actions.

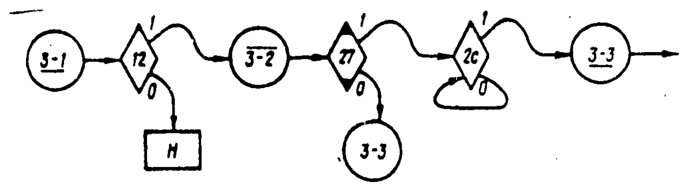


Figure 27. Example of Writing an Algorithm of Operator Activity

In the figure the following symbols are employed:

— an elementary statement — pressing and/or releasing a button, throwing a switch on or off, and so on. The numbers inside the circle represent the conventional number of the control organ (if the number is underlined the button is pressed; if it is overlined the button is released; if there is no line the button is pressed and released);

— a logical condition (lighting up a transparency); the number 1 is a branch which work takes if the logical condition is fulfilled, that is, if the transparency is lighted; the number 0 is the branch which work takes if the condition is not met, that is, if the transparency is not lighted;

— logical condition (extinguishing of the transparency); the number 1 means the transparency is extinguished; the number 0 means it is lighted up;

→ - the symbol → is a jump from one element of the algorithm to another;

— expectation of a certain moment in time before which the operation must not be performed; 1.8 seconds is the moment in time from the beginning of performance of the particular algorithm;

$\boxed{H}$ — signal for equipment malfunction.

The basic parameter of the model is the time of operator performance of the particular action (subtask), and as a result the time of performance of the entire job (task). The time of performance of the subtask is determined stochastically according to normal distribution by the Monte Carlo method. The average time of performance of subtask $\bar{t}_{ij}$ (average time necessary for operator j to perform subtask i) for typical subtasks can be obtained by calculation from the relationships and tables given in work [9]. Where there are special control and monitoring organs for which reference figures are not available, experiments are made with 30-40 operators as the result of which it is possible to obtain the value $\bar{t}_{ij}$ and mean quadratic deviation $\bar{\sigma}_{ij}$.

The mean probability of success in performance of subtask $\bar{P}_{ij}$ (the probability that operator j will successfully perform subtask i) is an important parameter of the model. The quantity $\bar{P}_{ij}$ can be obtained from the tables given in work [10].

The time of performance of subtasks and the probability of success depend on the level of tension and speed of the operators.

Simulation of operator activity involves sequential computation of the values of the variables for each subtask. The task is considered completed when both operators have successfully performed all subtasks in the allotted time.

The work of the modeling program begins with feeding the parameters and initial conditions of simulation to the main computer memory (see Figure 28 below). In this case the control punchcard contains the following quantities: T_j — maximum time of performance of the assignment by operator j; N_{π} — assigned number of iterations in the run; $N_{o\pi}$ — number of operators; N_i — number of subtasks in the algorithm.

The input values $n_{o\pi}$ and N_i are used to determine the dimensions of the matrix of raw data, after which the logical structure of the algorithm is fed to the main computer memory: i_j and $i_{j'}$ are the numbers of the subtasks performed by operators j and j'; d_{ij} are the numbers of the subtasks performed by operator j after performance of subtask i; I_i is the code of subtask type ($I_i = 1$ is a joint subtask; $I_i = 0$ is an individual subtask; $I_i = 3$ is an equipment subtask); E_i is the code of significance of the subtask ($E_i = 0$ is an insignificant subtask; $E_i = 1$ is a significant subtask).

In addition to logical quantities, each subtask uses the following parameters: $\bar{t}_{ij}$ — average time of performance of subtask i by operator j; σ_{ij} — mean quadratic deviation of time of performance of subtask i by operator j; $\bar{P}_{ij}$ — average probability of success in performance of subtask i; I_{ij} — early moment of completion of subtask i by operator j.

Then the operator characteristics are introduced: M_j — tension threshold of operator j; F_j — indicator of individual speed of operator j; G_j — level of demands of operator j.

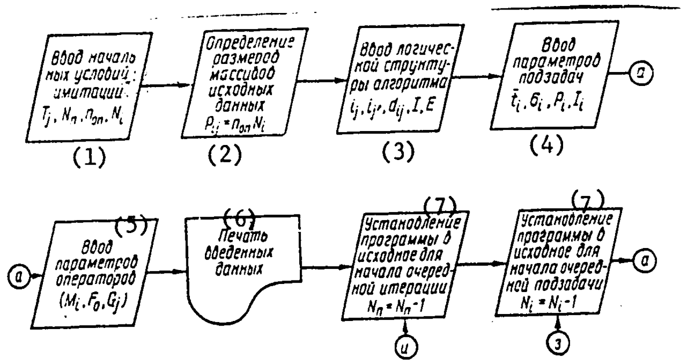


Figure 28. Feeding Parameters and Initial Conditions of Simulation.

Key: (1) Input of Initial Conditions of Simulation;
(2) Determination of Dimensions of Arrays of Raw Data;
(3) Input of Logical Structure of Algorithm;
(4) Input of Subtask Parameters;
(5) Input of Operator Parameters;
(6) Printing of Data Fed;
(7) Setting Program at Starting Point for Beginning of Next Iteration.

The parameters fed and the initial conditions are printed out to monitor correct compilation of data, and then the program is set in the initial state for the beginning of the next iteration and simulation of the subtask.

Selection of the operator is done in the first stage of modeling (see Figure 29 below). This is done by comparing times T^U_{ij} and $T^U_{ij'}$ used by operators j and j' by the moment of simulation of the particular subtask. The operator who has spent the least time is selected, and if the times are equal the operator with the lower number, that is operator j, is selected. If the operator selected must wait for the partner (this is determined by the logic of the algorithm, in other words by the value $d_{ij'}$), the actions of the other operator are simulated in advance. If this is not the case, a determination is made whether the operator must wait for the arrival of moments in time I_{ij} to perform the next subtask i. If time $T = I_{ij}$ has not yet arrived, then T^U_{ij} is set equal to I_{ij} and the operator whose actions are to be simulated is determined again. Next it is established whether subtask i is one of the joint type ($I_i = 1$). In this case the full time of the operator who worked longer is taken as the time of the slower operator.

For the operator finally selected, a computation is made of the urgency of situations, tension, and the cohesion of the group during performance of the particular subtask (see Figure 30 below). First the time $T_{ocт}$ left available to the operator to perform the entire task is determined, and the urgency of the situation is analyzed. If there is enough time remaining to complete all subsequent subtasks, the situation is considered nonurgent and the operator is not under tension, in other words tension is taken equal to one ($s_{ij} = 1$).

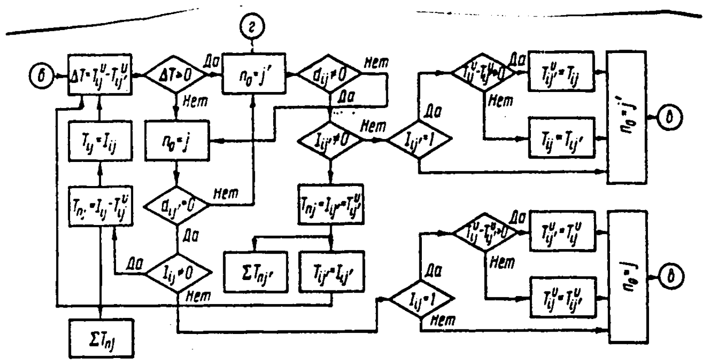


Figure 29. Operator Selection and Synchronization of Working Time.

Key: [Да — Yes;
Нет — No.]

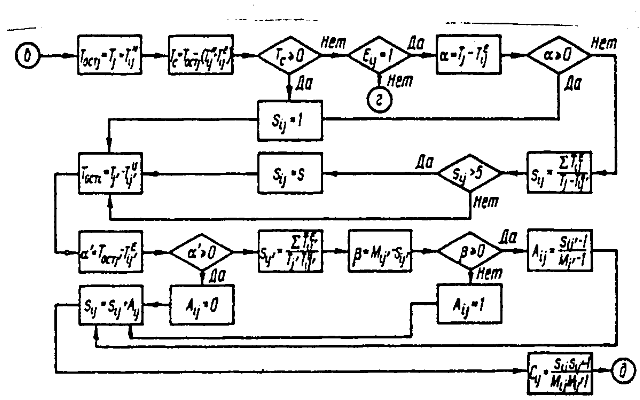


Figure 30. Computation of Urgency, Tension, and Cohesion

Key: [Да — Yes;
Нет — No.]

In the case where the time remaining is sufficient only to complete the significant subtasks, the program ignores insignificant subtasks, considering tension $s_{ij} = 1$. But if the time remaining is less than is needed to perform the remaining significant subtasks, operator tension is computed by the formula

$$s_{ij} = \frac{\sum_{i}^{N_{ij}} \bar{T}_{ij}^{E}}{T_j - T_{ij}^{V}}, \qquad (5.4)$$

where $\sum_{i}^{N_{ij}} \bar{T}_{ij}^{E}$ is the sum of average times of performance of remaining significant subtasks; N_{ij} is the number of significant subtasks in the tasks; T_j is the time of performance of an assignment (determined by initial modeling data); and, T_{ij}^{U} is the time spent for performance of preceding subtasks.

In the model group cohesion is a variable whose magnitude ranges from 0 to 1, and is a function of tension. The cohesion coefficient, which permits an assessment of the condition of the group, is determined for performance of each subtask by the formula

$$C_{ij} = \frac{s_{ij}s_{ij'} - 1}{M_j M_{j'} - 1}, \qquad (5.5)$$

where C_{ij} is the indicator of group cohesion; s_{ij} is the tension of the operator performing subtask i; s_{ij}' is the tension of the partner; M_j and M_j' are the tension thresholds of the operator and partner being simulated in the particular subtask (the tension threshold is the tension value at which activity is disrupted and the number of mistakes and time of performance of such tasks increase sharply).

Next the time of performance of subtask i by the operator is determined (see Figure 31 below). The pseudorandom quantity K_{ij} formed by generator 1 according to

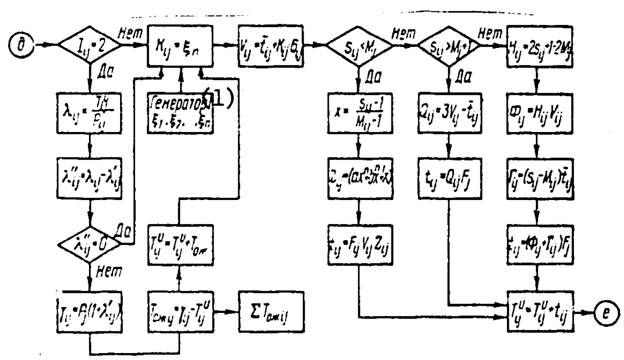


Figure 31. Determining Time of Performance of Subtask i.

Key: (1) Generator;
[Да — Yes;
Нет — No.]

($\bar{K}_{ij}$ = 0; σ_K = 1.0) is selected for this. The quantity K_{ij} is used to calculate the intermediate quantity U_{ij}, which takes account of the initial parameters of the subtask

$$V_{ij} = \bar{t}_{ij} + K_{ij}\bar{\sigma}_{ij}.$$

When calculating the time of performance of subtasks it is necessary to use the magnitude of total tension, which is equal to

$$\bar{s}_{ij} = A_{ij} + s_{ij}, \tag{5.6}$$

where A_{ij} is the magnitude of tension arising in the operator when the partner is under tension. It is taken as equal to zero if the partner feels no tension, that is, $s_{ij'} = 1$. Where $s_{ij} > M_{j'}$ and $A_{ij} = 1$, in the remaining situations it is determined by the formula

$$A_{ij} = \frac{s_{ij'} - 1}{M_j - 1}.$$

For the case where total operator tension is less than the threshold value ($\bar{s}_{ij} < M_j$), the time of performance of the subtask is computed in the following sequence:

(1) The standardized value of total operator tension is determined $x = \frac{\bar{s}_{ij} - 1}{M_j - 1}$;

(2) The coefficient of distortion of time of performance of the subtask under tension is calculated

$$Z_{ij} = ax^n + bx^{n-1} + \cdots + cx + d, \tag{5.7}$$

where a, b, and c are polynomial coefficients; n is the indicator of the power of the independent variable; and, d is the intersection;

(3) The time of performance of subtask i is determined taking into account the operator's individual speed (F_j)

$$t_{ij} = F_j V_{ij} Z_{ij}. \tag{5.8}$$

In the case where $s_{ij} > M_j + 1$, the time of performance of subtask i is determined from the expression

$$Q_{ij} = 3\bar{V}_{ij} - \bar{t}_{ij},$$

where Q_{ij} is the time of performance of the subtask without considering individual operator speed. Finally, we receive

$$t_{ij} = Q_{ij} F_j. \tag{5.9}$$

In the remaining cases, the following order is employed to determine t_{ij}:

(1) The intermediate quantities are computed

$$H_{ij} = 2\bar{s}_{ij} + 1 - 2M_j; \quad \Phi_{ij} = H_{ij} V_j; \quad L_{ij} = (s_{ij} - M_j)\bar{t}_{ij};$$

(2) The time of performance of the subtask is calculated by the formula

$$t_{ij} = (\Phi_{ij} + \bar{L}_{ij}) F_j. \tag{5.10}$$

The quantity $_{U}t_{ij}$ determined by one of the expressions (5.8)-(5.10) is added to total time T_{ij} used by the operator from the beginning of the iteration. Then comes the next stage of modeling, determining success and failure in performance of the current subtask (see Figure 32 below).

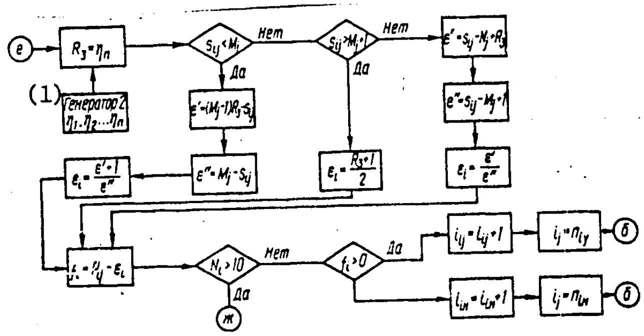


Figure 32. Determining Success and Failure.

Key: (1) Generator;
[Да — Yes;
Нет — No.]

Analysis of success and failure begins with selection of a pseudorandom number R formed by generator 2 according to a uniform law of distribution in a unit interval. This number is used to compute the criterial quantity ε_i. There are three variations for determining ε_i (depending on the value of current operator tension). In the case where $s_{ij} < M_j$, these intermediate quantities are found

$$\varepsilon_i' = (M_j - 1)R - s_{ij}; \quad \varepsilon_i'' = M_j - s_{ij},$$

and they are then used to compute the criterial value

$$\varepsilon_i = \frac{\varepsilon_i' + 1}{\varepsilon_i''}. \tag{5.11}$$

where $s_{ij} > M_j + 1$, the following expression is used

$$\varepsilon_i = \frac{R + 1}{2}. \tag{5.12}$$

In the remaining situations, intermediate quantities are determined by these formulas

$$\varepsilon_i' = s_{ij} - M_j + B; \quad \varepsilon_i'' = s_j - M_j + 1,$$

after which we finally find

$$\varepsilon_i = \frac{\varepsilon_i'}{\varepsilon_i''}. \tag{5.13}$$

The value of the criterial quantity ε_j, obtained from one of the expressions (5.11)-(5.13) is used for comparison with a given probability of success in performance of subtask i:

$$f_i = \bar{P}_{ij} - \varepsilon_i.$$

In this case $f_i > 0$ signifies successful completion of the subtask; other cases are continued failures. The success or failure is registered by a success or failure register, and then the subtask which must be performed in the next step is determined.

The modeling sequence includes an evaluation of the level of operator demands, which takes the operator's purposefulness into account (see Figure 33 below).

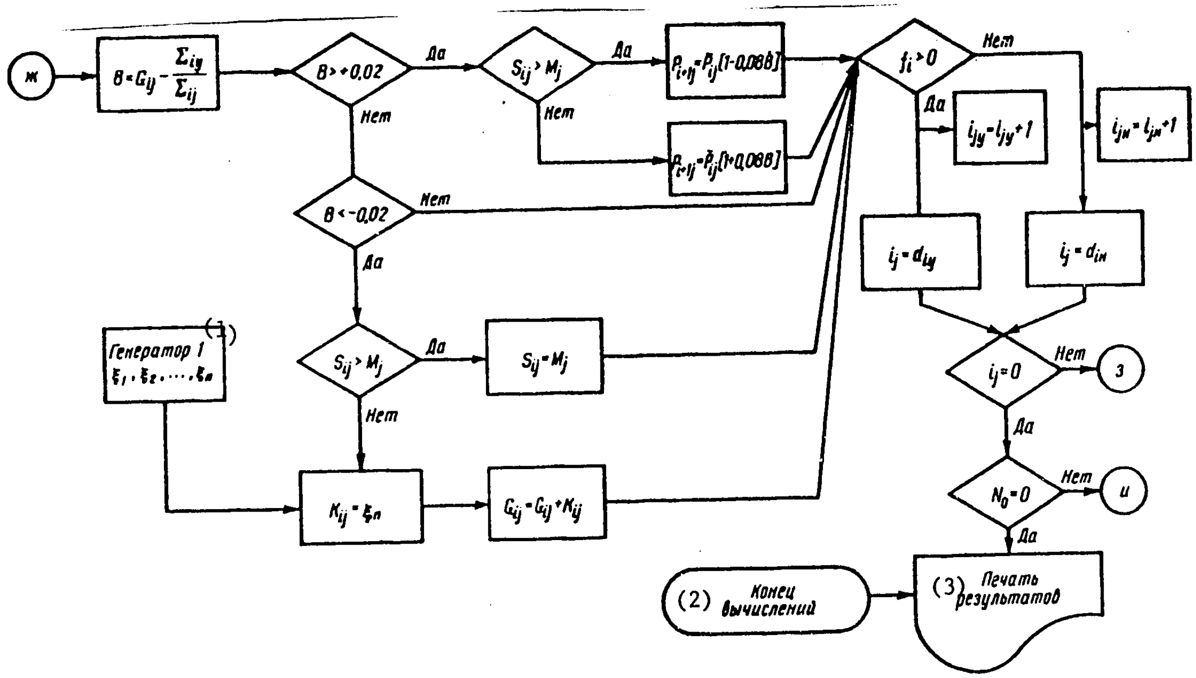


Figure 33. Evaluation of the Level of Demands and Completion of Computation.

Key: (1) Generator;
(2) End of Computations;
(3) Printing of Results;
[Да — Yes;
Нет — No.]

To analyze the influence of this characteristic the degree of divergence between the operator's goals and the results of the operator's labor are computed for each subtask:

$$B = G_j - \frac{\sum_{i_y=1}^{i_y} i_y}{\sum_{i_j=1}^{i_j} i_j}, \qquad (5.14)$$

where B is the degree of divergence in goals; G_j is the level of demands of operator j: $j; \sum_{i_y=1}^{i_y} i_y$ is the number of subtasks successfully performed by the operator; $\sum_{i_j=1}^{i_j} i_j$ is the total number of subtasks performed by operator j.

After this one of five situations may arise with using the quantity B to correct operator activity.

If B > +0.02, then two cases are possible:

(1) where $s_{ij} > M_j$, the value of the probability of successful performance of the next subtask by operator j is lowered:

$$P_{i+1,j} = \overline{P}_{ij}[1 - 0{,}08B];$$

(2) where $s_{ij} \leqslant M_j$, the value of the probability of successful performance of the subtask by the operator increases

$$\overline{P}_{i+1,j} = \overline{P}_{ij}[1 + 0{,}08B].$$

If the divergence in goals is within the range $-0.02 < B < +0.02$ no correction of operator activity is made. If $B < -0.02$, two cases are also possible:

(1) where $s_{ij} > M_j$, the magnitude of ongoing operator tension is restricted to the threshold value ($s_{ij} = M_j$);

(2) where $s_{ij} \leqslant M_j$, the level of operator claims is increased by quantity k_{ij}, formed by random number generator 1 according to the normal law ($\overline{K}_{ij} = 0, 0, \sigma_{ij} = 1.0$).

The computations of one iteration are completed when the numbers of the next subtasks of both operators are equal to zero; in this case the number of remaining iterations until the end of the run N_π is analyzed. If $N_\pi \neq 0$, the program is set in the initial position for the beginning of the iteration of the algorithm; in the opposite case, the necessary results of modeling are printed out and the process of simulation is stopped.

The simulation model of operator activity was realized on a Minsk-32 computer. The computer program is given in Appendix 1.

The possibilities of using a model can be illustrated with the example of estimating the necessary level of automation of one of the models of monitoring-testing equipment and evaluating the efficiency of the testing process.

As W, the efficiency of the testing process, we will take the ratio of the number of subtasks successfully performed by the operator to the total number of subtasks. Proceeding from this it is interesting to learn how testing efficiency depends on limiting time T_j of performance of the assignment by the operator. In the process of modeling this relationship was investigated while changing the values of T_j from 220 and 270 seconds. Efficiency depends signficantly on the individual characteristics of the operator. In the process of modeling, therefore, we simulated a normal operator ($F_j = 1.0$), a fast operator ($F_j = 0.7$), and a slow operator ($F_j + 1.3$). Figure 34 below presents the results of the modeling. It

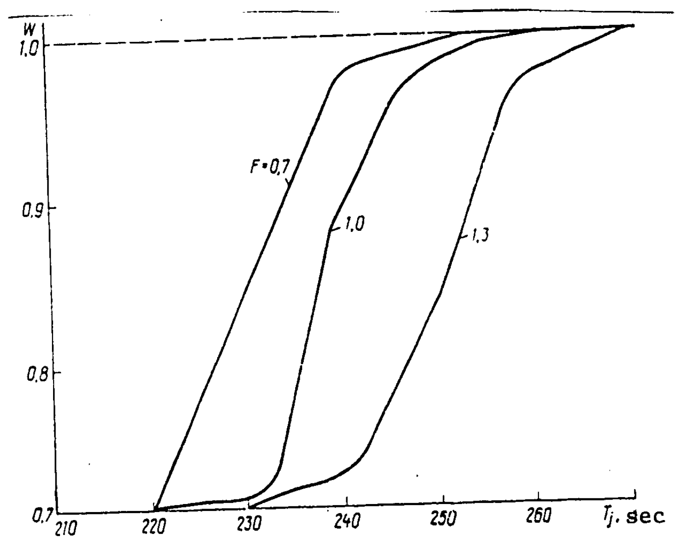


Figure 34. Dependence of Efficiency of Algorithm Performance on Limiting Time of Operator Work.

became clear in the process of investigation that the magnitude of the threshold of tension M_j does not have a significant impact on W. Therefore, an average value $M_j = 2$ was adopted.

The results of modeling showed that a fast operator ($F_j = 0.7$) works more efficiently, while a slow operator ($F_j = 1.3$) works less efficiently. For example, where $T_j = 240$ seconds, the efficiency of the testing process with the fast operator was $W_{0.7} = 0.98$, while for the normal operator it was $W_{1.0} = 0.89$, and for the slow operator $W_{1.3} = 0.74$. This enables us to define work standards for operators depending on the assigned efficiency of the testing process.

Analysis of the results of modeling showed that where T_j is small (less than 220 seconds), the efficiency of the process is low ($W = 0.71$). As T_j increases it rises, and is equal to one for a fast worker when $T_j = 250$ seconds, for a normal operator where $T_j = 260$ seconds, and for a slow operator when $T_j = 270$ seconds.

Therefore, when testing large batches of instruments with adequate time highly efficient testing can be achieved. If it is necessary to test a large number of instruments in a limited time, the efficiency of the tests becomes inadequate. In this case the need arises to automate the monitoring and testing equipment.

Synthesis of an Information Simulation Model of Group Operator Activity

The proposed model simulates the interrelated group activity of operators when processing information. The essential features of this activity are that a group consisting of n operators is given a certain amount of information H_Σ, which takes a certain time T to process. The information subject to processing is divided into parts in equal proportions according to the number of information channels (operators), thus establishing a certain initial intensity of information flows

$$F_j = \frac{H_\Sigma}{nT}, \tag{5.15}$$

where F_j is the initial intensity of the information flow in information channel j; H_Σ is the total amount of information being processed; n is the number of information channels; and, T is the time allocated for information processing.

The operators process the information signals presented to them, forming appropriate actions with elements of the control consoles according to assigned algorithms. In the course of work the differences in the intensity of flows of information presented and processed in each channel are measured. Information (signals) correctly processed by the operators is summed in the resulting information receiver. The ratios of the information submitted and processed are calculated with a selected step to quantify time Δt for each operator:

$$a_{ij} = \frac{N_{ij}^0}{N_{ij}^n}, \tag{5.16}$$

where a_{ij} is the indicator of quality of work for the operator in information channel j in work cycle j; N_{ij}^0 is the number of signals correctly processed by the operator in information channel j including work cycle i; N_{ij}^n is the total number of signals presented to the operator in information channel j, including work cycle i.

The values of a_{ij} are used to compute standardized coefficients of information loading of the channels in the next cycle:

$$b_{i+1,j} = \frac{a_{ij}}{\sum\limits_{j=1}^{n} a_{ij}}, \tag{5.17}$$

where $b_{i+1,j}$ is a standardized coefficient of information loading of channel j in the next cycle (i + 1); and, $\sum\limits_{j=1}^{n} a_{ij}$ is the sum value of the indicators of work quality of the group of operators in step i.

The intensity of the information flow which should be presented to the operator in the next step, taking into account the activity of this individual and of the entire group, is determined from the expression

$$F_{i+1,j} = \frac{b_{i+1,j}(H_\Sigma - H^0_{\Sigma i})}{T - T'_i}, \tag{5.18}$$

where $H^0_{\Sigma i}$ is the total amount of information correctly processed by the group of operators by the completion of cycle i; T'_i is the time from the beginning of work to the completion of cycle i.

Thus, a lowering of the quality of work by any operator in the group causes a slight reduction in the information loading of this operator by a corresponding increase in the loading of the operators. Where the proposed method is used, the following are selected as criteria of group activity:

a. The quality of group activity, defined by the expression

$$Q = \frac{s_2}{s_1}, \tag{5.19}$$

where s_1 is the total number of information signals presented to the group of operators and s_2 is the total number of signals correctly processed by the group;

b. The efficiency of group work, measured by the ratio of the initial intensity of the total information flow to the current value of intensity of the total information flow:

$$E = \frac{F_\Sigma}{F_{\Sigma i}}, \tag{5.20}$$

where $F_\Sigma = \frac{H}{T}$ is the initial intensity of the total information flow; $F_{\Sigma i} = \frac{H_\Sigma - H^0_\Sigma}{T - T'}$ is the intensity of the total information flow in step i. Thus, expression (5.20) assumes the form

$$E = \frac{H_\Sigma(T - T')}{T(H_\Sigma - H^0_{\Sigma i})}; \tag{5.21}$$

c. Coordination and smoothness of operator work, determined by the uniformity of the coefficients of information loading of the channels:

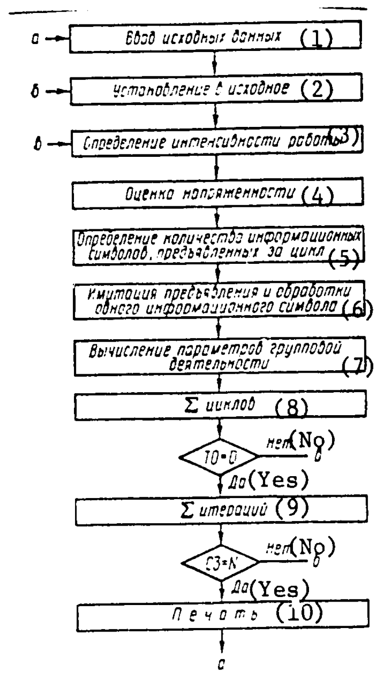
$$Z = n^n \prod_{j=1}^{n} b_j, \tag{5.22}$$

where n^n is a standardizing coefficient, and b_j is the coefficient of information loading of channel j in the final cycle.

The integrated criterion of group activity in the model is the value of the threshold magnitude of intensity of the total information flow. With this in mind the initial intensity of the information flow for the group of operators being modeled is increased by a certain quantization step from run to run.

This is done either by increasing the flow or reducing the time necessary to process it. The magnitude of intensity of the information flow at which the group could not handle its assignment (did not process all information) is considered the threshold for the particular group.

Figure 35 below shows a flowchart of the simulation model. The model works as



Key: (1) Input of Raw Data;
(2) Setting in Initial Position;
(3) Determining Work Intensity;
(4) Evaluation of Tension;
(5) Determining Number of Information Symbols Presented in a Cycle;
(6) Simulation of the Presentation and Processing of One Information Symbol;
(7) Computation of the Parameters of Group Activity;
(8) Σ Cycles;
(9) Σ Iterations;
(10) Printing.

Figure 35. Flowchart of the Simulation Information Model lf Operator Group Activity.

follows. Before simulation is begun the raw data are fed to the program. The data may be divided into three types. The first type comprises raw data that simulates characteristics of each operator separately: time spent by the operator to process information R (time of simple sensomotor reaction), mean quadratic deviation σ of reaction time, tension threshold M, probability of error-free work P, and the polynomial coefficients of tension* (5.7). The second type comprises raw data that characterize the group as a whole: amount of information processes H, and time T in which the information submitted must be

*Section 3 gives a detailed consideration of the process of obtaining polynomial coefficients of tension.

APPROVED FOR RELEASE: 2007/02/09: CIA-RDP82-00850R000500020049-1

processed. The third type comprises parameters necessary for the work of the model (iterations) and for printing. In addition, the number of operators in group M is an important parameter that is essential for the work of the model and to describe the group. The order of inputting data to the program is shown in Figure 36 below.

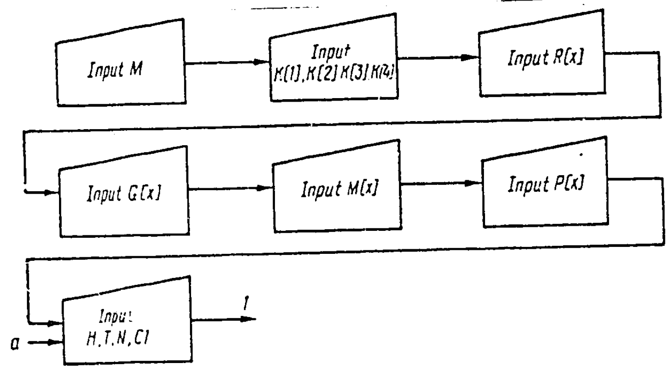


Figure 36. Inputting Raw Data.

All parameters must be reset in advance for the work of the model. In this case they are broken into two groups: parameters which are reset before each iteration, and parameters which are reset more than once within each iteration. The order of resetting is shown in Figure 37 below.

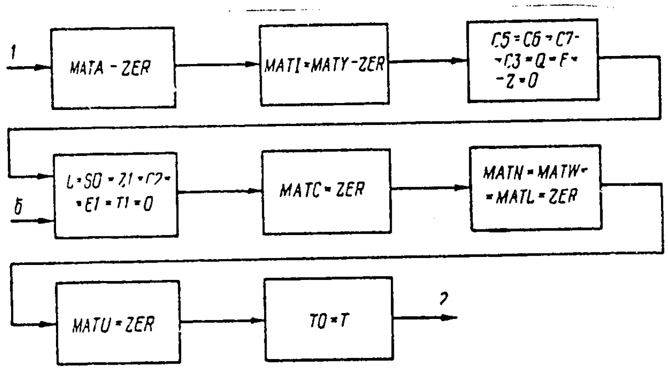


Figure 37. Resetting the Model.

The work of the model begins by simulating the breakdown of the intensity of the total information flow F by channels. In the first stage here the presentation of information flow F[x] = F/M to each operator at uniform initial intensity is simulated. In subsequent stages the intensities of the information flows are determined depending on the coefficients of information loading of the channels B[x] and the current value of the intensity of the total information flow F1. This stage of work of the model is shown in Figure 38 below.

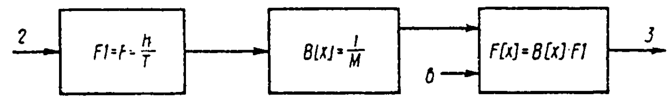


Figure 38. Distribution of the Initial Information Flow by Channels.

Each computation of the intensity of information flows is done after a time interval during which at least one operator must process one information symbol. During this time the remaining operators should process one or more information symbols. A special subroutine was devised for the next stage of computation in each iteration. The basic feature of this subroutine is that it presents all remaining information symbols HO in the time remaining to the group TO. The time during which each of the operators must process one information symbol is defined as T[x] = 1/F[x]. This time allows an evaluation of the tension of each operator, which is the ratio of the time required to process the information in an ordinary state R[x] to time remaining: S[x]R[x]/T[x]. The magnitude of tension S[x] and the polynomial coefficients K[1], K[2], K[3], K[4], and K[5] make it possible to evaluate the influence of tension on information processing time by determining the distortion coefficient of time D[x]. Where tension is greater than the threshold M[x], the time distortion coefficient is taken as equal to a constant value D[x] = 2 so that it is known that the operator will not handle the information processing in time. The computer algorithm for evaluating tension is shown in Figure 39 below.

During the simulation process it was established that if even one of the operators has a tension value twice as high as the threshold (S[x] > 2M[x]), the tension value for the other operators will also be above the threshold value. In other words, performance of the work by the group is disrupted by tension.

Figure 40 below shows the algorithm for computing the number of information symbols U[x] presented to each operator in one cycle. The quantity C[x] represents additional information (number of symbols) presented to an operator who is working successfully to compensate for the failures of the operator who is behind, and INT is a symbol that signifies rounding to the lower whole number.

Next the model simulates the processing of information symbols by each of the operators (see Figure 41 below). Pseudorandom numbers are used here. The first pseudorandom number, uniformly distributed in the interval (0, 1), is used to select the action for the assigned probabilities of alternatives which add up to one. If P[x] - RND(x) > 0, we consider that the information was processed correctly; in the opposite case we consider it to have been done incorrectly. The second pseudorandom number is used to determine the time required to process one information symbol RO, which we consider to be distributed by the normal law.

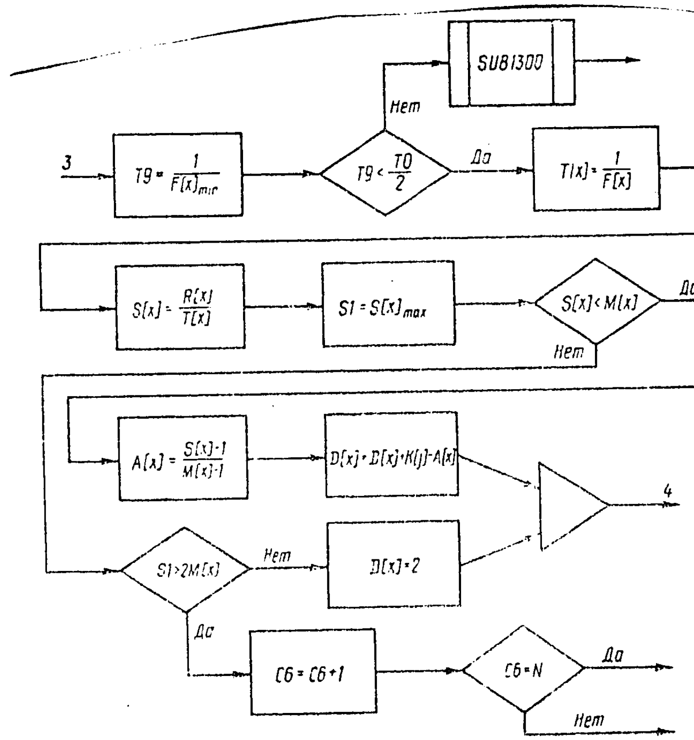


Figure 39. Evaluating Operator Tension.

Key: [Дa — Yes;
Hem — No.]

It is assumed here that if RO < 0.15 seconds, it is necessary to take RO = 0.15 seconds in later calculations. If RO is greater than the time required to process one information symbol T[x], the operator is reckoned to have failed.

Figures 42 and 43 below show the computation of the parameters necessary for further work of the model: the coefficients of information loading of channels B[x], ongoing time T1, the number of information signals remaining for the group to process HO, the time left available to the group TO, and parameters for evaluation of group activity (quality of group activity Q, efficiency of group activity E, and coordination of operator work Z).

Depending on the goals of modeling, the data of interest may be printed out after each iteration (see Figure 44 below) and after calculating N iterations (see Figure 45 below).

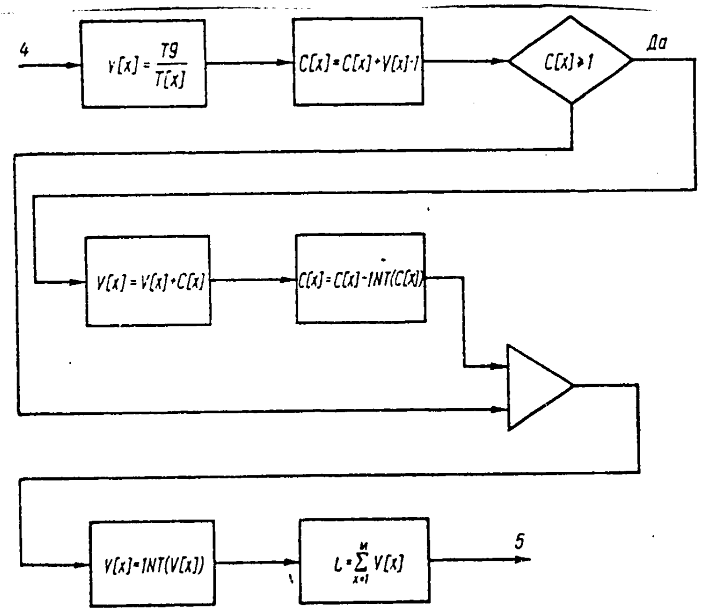


Figure 40. Determining the Number of Information Signals Presented to Each Operator in a Cycle.

The modeling program in the BASIC language and the symbols for the variables are given in Appendices 2 and 3 respectively.

To assess the possibility of practical use of the proposed model of interrelated activity by a group of operators, evaluate the workability of the criteria given, and assess possible work regimes, statistical modeling of interrelated group activity was done in an information overload regime.

The modeling was done on an M-6000 digital computer. As initial data, which were not changed from one "run" to another, we selected the number of operators in a group M = 3, a polynomial of tension the same for each operator of the group with coefficients K[1] = 1, K[2] = -2.35, K[3] = 3.472, and K[4] = -1.829, processing time for information R[x] = 0.4 seconds equal for all operators, as was mean quadratic deviation G[x] = 0.1 seconds, threshold of tension M[x] = 2. The time during which the information presented had to be processed T = 10 seconds was also made unchanging through all iterations. The variable parameters are the number of information symbols H which the group must process, and the probability of error-free work P[x] for each operator of the group.

The computations were stopped and data of interest were printed out after 10 successful iterations in a "run" or after 10 failures owing to tension. Table 4 below presents the initial data and results of modeling.

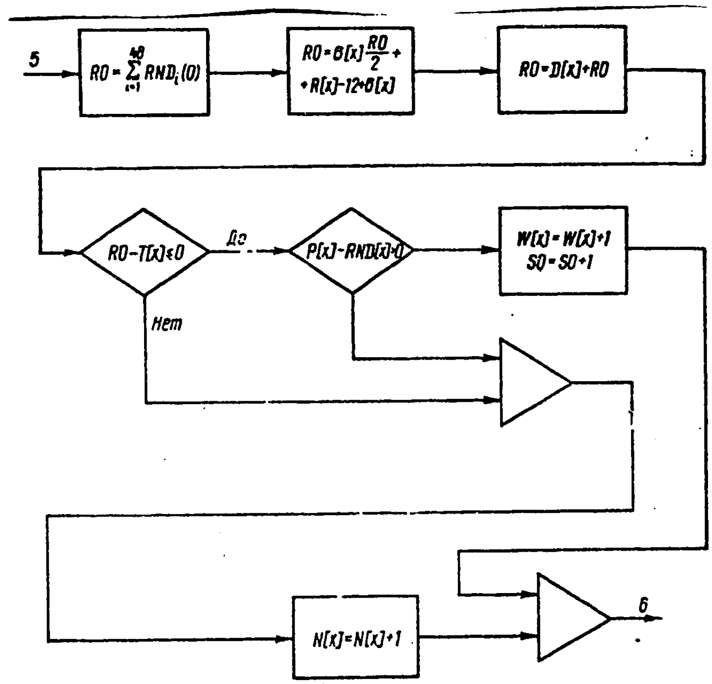


Figure 41. Simulating the Process of the Operator's Processing of an Information Symbol.

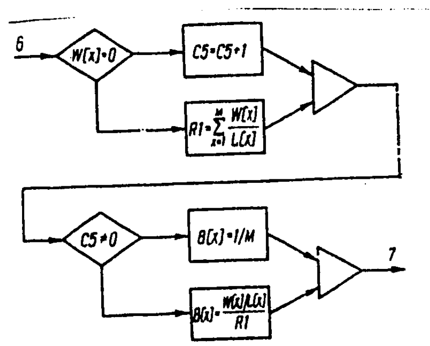


Figure 42. Determination of the Coefficients of Information Loading of the Channels.

The following relationships were constructed on the basis of the results of statistical modeling: a dependence of the coordination and smoothness of operator work on the number of information signals presented to the group, Z = F(H);

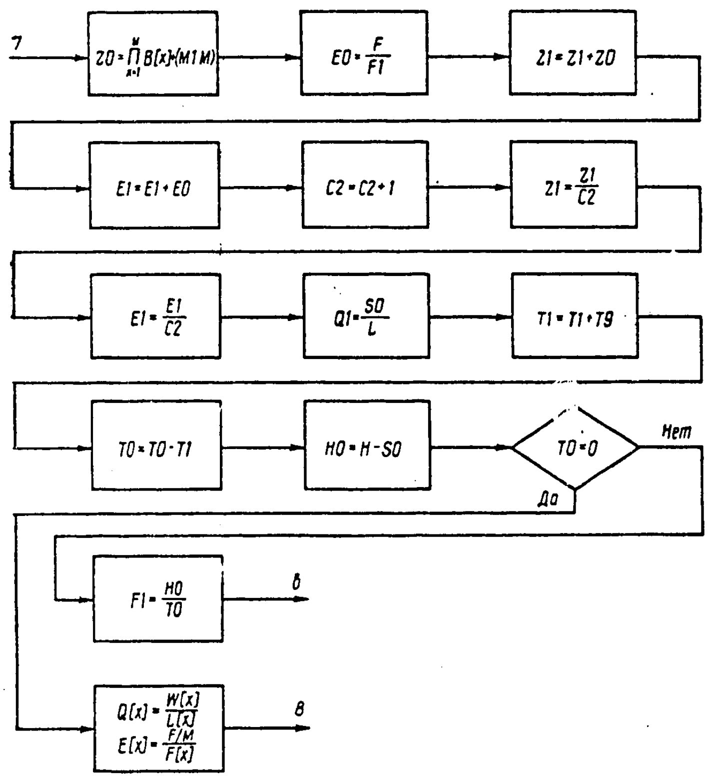


Figure 43. Determination of the Parameters of Operator Group Activity.

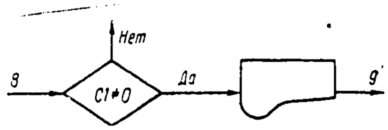


Figure 44. Printing Out the Results of One Iteration.

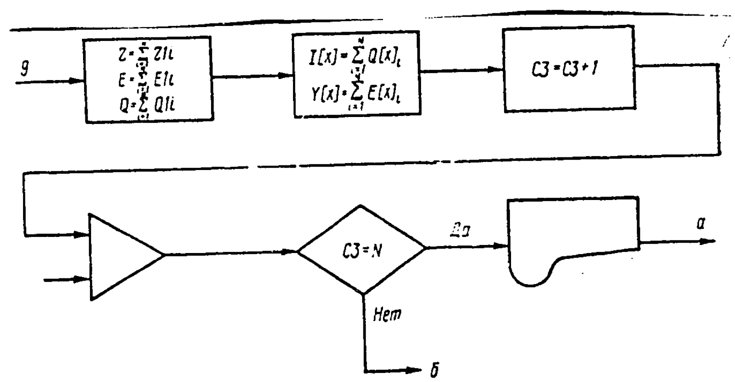


Figure 45. Printing Out the Results of N Iterations

a dependence of the efficiency of group work on the number of information symbols E = F(H); a dependence of the quality of group activity on the number of information symbols Q = F(H) for three groups of operators. The first group included two operators with a probability of error-free work P[1] = P[2] = 0.9 and one with a probability P[3] = 0.7. The second group comprised operators with differing probabilities of error-free work: P[1] = 0.9, P[2] = 0.8, and P[3] = 0.7. The third group represented the activity of operators with the same probability of error-free work: P[1] = P[2] = P[3] = 0.8. The relationships obtained for Z = F(H), E = F(H), and Q = F(H) for each of the groups are presented in Figures 46, 47, and 48 respectively.

An analysis of the relationship Z = F(H) permits the conclusion that when the number of information symbols is increased one should expect the smoothness and coordination of work to remain constant or rise slightly until the time when failure owing to tension occurs for the group. After the number of information signals is increased to the level when tension failures begin to appear, there is a sharp drop in smoothness and coordination of work. When the number of information signals is increased further this drop becomes more fluid. The relationships E = F(H) and Q = F(H) have a similar appearance.

Analysis of the coordination and smoothness of work of each of the three groups of operators revealed that despite the maximum uniformity in the third group (P[1] = P[2] = P[3] = 0.8), its smoothness of work after the onset of tension-caused failures was not much higher than that of the second group, which had operators with different probabilities of error-free work. In this case the quality of group activity and efficiency of work are higher in groups which have leaders, evidently because in this case they will compensate for the poor work of one of the other operators.

This also explains the fact that during simulation of the work of the uniform group the number of iterations that ended in failures caused by tension was greater than in the other groups.

Table 4. Initial Data and Results of Modeling.

Number of Variation	P1	P2	P3	H	T	C1	N	Z	E	Q	C6
1	0,9	0,9	0,7	30	10	0	10	0,945	0,917	0,832	0
2	0,9	0,9	0,7	40	10	0	10	0,951	0,848	0,755	0
3	0,9	0,9	0,7	50	10	0	14	0,678	0,539	0,483	4
4	0,9	0,9	0,7	60	10	0	15	0,615	0,525	0,459	5
5	0,9	0,9	0,7	70	10	0	17	0,51	0,518	0,447	7
6	0,9	0,8	0,7	30	10	0	10	0,943	0,928	0,826	0
7	0,9	0,8	0,7	40	10	0	10	0,948	0,876	0,777	0
8	0,9	0,8	0,7	50	10	0	17	0,560	0,446	0.405	7
9	0,9	0,8	0,7	60	10	0	18	0,497	0,476	0,381	8
10	0,9	0,8	0,7	70	10	0	20	0,414	0,425	0,349	10
11	0,8	0,8	0,8	30	10	0	10	0,967	0,905	0,819	0
12	0,8	0,8	0,8	40	10	0	11	0,876	0,687	0,638	1
13	0,8	0,8	0,8	50	10	0	17	0,567	0,444	0,414	7
14	0,8	0,8	0,8	60	10	0	18	0,534	0,332	0,307	8
15	0,8	0,8	0,8	70	10	0	15	0,313	0,279	0.230	10

The results obtained correlate significantly with experience in operator activity. Thus, even successful performance of a task in an ergatic system usually involves unequal personal contributions by the individual operators. It is almost always possible to identify an operator who guides the general strategy of the group (the leader), whereas the other partners, involuntarily and often not fully aware of it, subordinate themselves to the leader's actions. It is important to observe here that each operator may under certain conditions take the role of leader.

Thus, the results of modeling showed that the criteria of group activity proposed in the model are correct and to some extent reflect the processes that take place within a group when working under conditions of information overloads.

Factor Models of Operator Activity

The psychophysiological factors of operator activity are not subject to direct measurement. Therefore, they are frequently investigated by reflection in observed or specially elicited actions by the human operator. One of the variations of these actions is "testing" — a natural or specially designed influence on the psyche which evokes a reflection of latent characterisic F which manifests itself in an objectively recorded action Z, where Z is an unknown function of F. In other words, the factor structure of operator activity can be disclosed by the techniques of factor analysis based on the results of testing.

The mathematical essence of factor analysis is as follows [11]. An empirical matrix of standardized data $Z = [z_{ij}]$ is given where each z_{ij} is an evaluation of individual j according to test i. It is assumed that

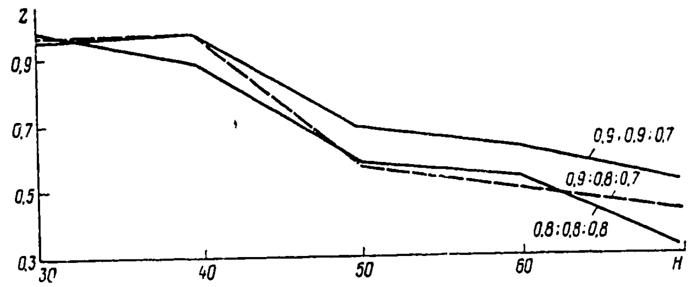


Figure 46. Dependence of the Coordination and Smoothness of Work by Groups of Operators on Amount of Information Presented.

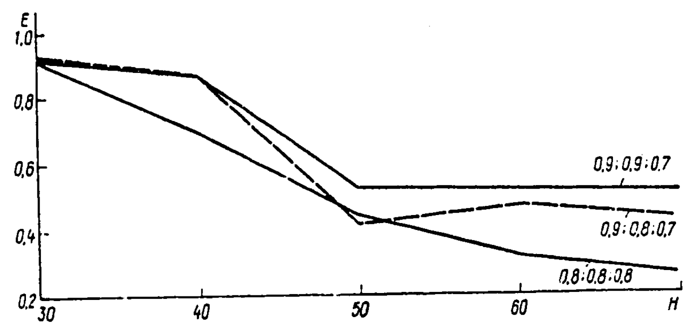


Figure 47. Dependence of the Efficiency of Work of Groups of Operators on the Amount of Information Presented.

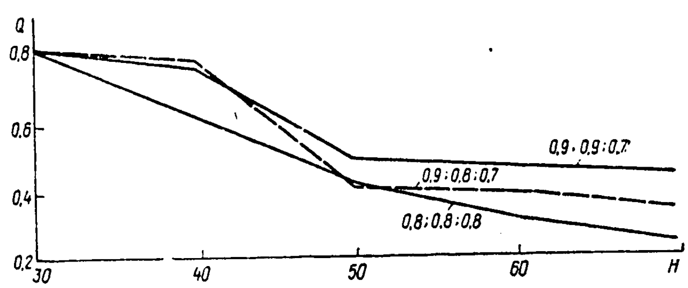


Figure 48. Dependence of the Quality of Group Activity on the Amount of Information Presented.

$$z_{ij} = l_{i1}\varphi_{1j} + l_{i2}\varphi_{2j} + \cdots + l_{ir}\varphi_{rj} + \cdots + l_{ik}\varphi_{kj}, \qquad (5.23)$$

where l_{ir} is the factor weight of test i for factor r; and, ϕ_{rj} is the r-factor for individual j.

The matrix of factor weights has the following appearance.

$$L = \begin{vmatrix} l_{11}l_{12} & \ldots & l_{1r} & \ldots & l_{1k} \\ l_{21}l_{22} & \ldots & l_{2r} & \ldots & l_{2k} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ l_{i1}l_{i2} & \ldots & l_{ir} & \ldots & l_{ik} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ l_{p1}l_{p2} & \ldots & l_{pr} & \ldots & l_{pk} \end{vmatrix}.$$

The matrix of factors may be represented as follows

$$F = \begin{vmatrix} \varphi_{11}\varphi_{12} & \cdots & \varphi_{1j} & \cdots & \varphi_{1N} \\ \varphi_{21}\varphi_{22} & \cdots & \varphi_{2j} & \cdots & \varphi_{2N} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \varphi_{r1}\varphi_{r2} & \cdots & \varphi_{rj} & \cdots & \varphi_{rN} \\ \varphi_{k1}\varphi_{k2} & \cdots & \varphi_{kj} & \cdots & \varphi_{kN} \end{vmatrix}.$$

Then on the basis of (5.23) we may write that Z = LF. In turn, ZZ' = R, where Z' is a transposed empirical matrix; and, R is a matrix of correlations among tests. Then

$$R = LL', \qquad (5.24)$$

where L' is a transposed matrix of factor weights.

The equation (5.24) expresses Thurston's basic theorem of factor analysis. It follows from it that the elements of the main diagonal of matrix R represent the sums of the squares of the elements of the corresponding lines of matrix L, on each line of which are the factor weights of a certain indicator i for all the common factors, that is l_{i1}, l_{i2},..., l_{ir}, ..., l_{ik}. The squares of these factor weights are interdependent: $l_{i1}^2 + l_{i2}^2 + \cdots + l_{ir}^2 + \cdots + l_{ik}^2 = h_i^2$,

where h_i^2 is the generality, that is, that part of the test dispersion which depends on the common (general) factors.

Factor models were used to identify the general psychophysiological structure of the activity of operators of automated control systems (ASU's) and to clarify the microstructure of operator activity in a specific ASU.

As an example let us consider investigation of factor mathematical models of the microstructure of operator activity.

The activity of the operator in an ergatic system is a dynamic organization of actions and operations directed to performing definite labor tasks. As a rule operators of ergatic systems during their work perform not one, but several tasks, each of which presupposes performance of a definite set of actions in an assigned sequence, that is, execution of a definite algorithm. In the general case, therefore, operator activity has a hierarchical structure consisting of a series of algorithms A_1, A_2, ..., A_n, each of which includes a set of actions (subtasks) $\{z_{j1}, z_{j2}, \ldots, z_{jk}\}$. In its turn, each subtask consists of a subset of elementary operations $\{s_{i1}, s_{i2}, \ldots, s_{iM}\}$. Thus, investigation of the microstructure of concrete operator activity requires determination of the hierarchical structure, that is, computing in a noncontradictory and convenient manner the levels of collective and individual activity, work regimes, and tasks and subtasks performed by operators in each particular case. Structural analysis [3], which envisions sequential performance of the following actions, may be used for this purpose:

1. determining the range of duties for each of the operators of the ergatic system;

2. identifying work regimes when performing operational tasks;

3. identifying subsets of tasks that must be performed in each work regime.

Based on analysis of the activity of an ASU operator, three basic algorithms for performing operational tasks were identified:

1. monitoring the parameters of one of the elements of the ASU;

2. changing the regime of functioning of the ASU;

3. performing the job of external control contour for the system.

Analysis of the instructions that control procedures for performing these tasks made it possible to identify the characteristic actions performed with system control elements and the logical conditions of their application.

A comparative analysis of quantitative evaluations of algorithms, done by the criteria proposed in work [4], shows (see Table 5 below) that despite its small total number of elements, algorithm three has the highest values for relative numbers of efficient operators and logical conditions, logical complexity, and dynamic intensity. This allows it to be classified with the most difficult tasks in the set under consideration. Therefore, algorithm three is the most interesting as an object for further investigation.

A natural experiment was conducted to clarify the psychophysiological structure of the chosen algorithm of activity. Operators of the particular ASU were enlisted as test subjects. During the process of executing the algorithm the time spent by each operator for error-free performance of work cycles was recorded and the average time of performance of each action was determined.

The second stage of investigation was to test this group of operators with equipment and questionnaire techniques. As a result more than 30 variables, which are shown in Table 6 below were obtained and a matrix of intercorrelations was calculated. A standard computer program in Fortran was used to factor the correlation matrix [2, p 255].

Table 5. Quantitative Characteristics of Algorithms

Evaluation Criteria	Algorithms 1	2	3
Number of Afferent Operators in the Algorithm	20	32	15
Number of Efferent Operators in the Algorithm	14	21	16
Number of Logical Conditions in the Algorithm	6	7	7
Total Number of Elements of Algorithms	40	60	38
Relative Number of Afferent Operators	0.50	0.53	0.40
Relative Number of Efferent Operators	0.35	0.35	0.43
Relative Number of Logical Conditions	0.15	0.11	0.16
Stereotypic Quality of Algorithm	35	54	31
Logical Complexity of Algorithm	6	7	7
Average Time of Performance of Algorithm	90	40	20
Total Dynamic Intensity	0.44	1.5	1.9
Efferent Dynamic Intensity	0.15	0.52	0.80
Afferent-Logical Intensity	0.28	0.97	1.15

Table 6. Variables Investigated

Number of Indicator	Name of Indicator
	Time Indicators of Performance of the Algorithm
1	Switching off signals
2	Pressing keys on console
3	Finding and pressing button j on console
4	Switching off safety device
5	Resetting control elements
6	Perceiving information group m
7	Finding and pressing control element
8	Transmitting information on execution of the algorithm
	Testing Indicators
9	Individual speed
10	Thresholds of tempo-based tension
11	Addition with switching (productivity)
12	Addition with switching (relative frequency of errors)
13	Entangled lines (productivity)
14	Entangled lines (relative frequency of errors)
15	Arrangement of numbers (productivity)
16	Arrangement of numbers (relative frequency of errors)
17	Landolt rings (productivity)
18	Landolt rings (relative frequency of errors)
19	Compasses (productivity)
20	Compasses (relative frequency of errors)
21	Memory (absolute indicator)
22	Establishing patterns (productivity)

[Table 6 continued next page]

[Table 6 continued]

Number of Indicator	Name of Indicator
	Testing Indicators
23	Establishing patterns (relative frequency of errors)
24	Number-letter combinations (success coefficient)
25	Time sense (average value)
26	Time of simple reaction to light
27	Time of complex reaction to light
28	KChSM [expansion unknown]
29	Tepping test (difference)
30	Tepping test (general)
31	Coordination (success coefficient)

As a result of the calculations made, four basic factors which determine the patterns of the process under study were identified. Table 7 below shows the factor matrix obtained in the course of 11 iterations of rotation. Our problem does not

Table 7. Factor Matrix

Number of Variable	Factors 1	2	3	4
1	0.13776	0.84482	0.25345	0.30747
2	0.18747	0.84279	0.23733	0.27796
3	0.12859	0.84773	0.25803	0.31129
4	0.88965	0.07203	-0.09562	-0.10179
5	0.93261	-0.02203	-0.64390	-0.06140
6	0.91906	-0.00381	-0.07544	-0.06265
7	0.66369	0.18100	0.08561	0.07721
8	0.52286	0.21463	-0.22535	0.46156
9	0.29714	0.57004	-0.17729	-0.12938
10	-0.24495	0.35232	-0.50921	0.21786
11	0.16032	-0.15007	0.62921	-0.09149
12	0.21256	0.20619	-0.51232	0.29727
13	0.14414	-0.46291	0.34256	0.14502
14	0.19368	-0.12890	-0.27466	-0.24039
15	-0.36464	1.9794	0.26685	0.05320
16	0.35315	-0.05695	0.21901	0.13094
17	-0.06330	0.19126	-0.02799	0.53608
18	0.26126	0.22748	0.19601	0.20358
19	-0.19286	0.12661	0.59552	0.26938
20	0.28078	-0.14145	-0.37763	-0.16084
21	0.05884	-0.11983	0.04046	0.53855
22	-0.00749	+0.08774	0.02430	0.55000
23	0.11294	-0.10201	-0.53937	0.26602
24	-0.17331	-0.11019	0.56374	0.18685
25	-0.17837	0.40425	0.12268	-0.19104

[Table 6 continued next page]

[Table 7 continued]

Number of Variable	Factors			
	1	2	3	4
26	0.07675	0.43620	-0.11427	-0.18166
27	0.08123	0.06523	0.20956	-0.05044
28	0.17049	-0.12080	-0.16138	0.59780
29	-0.13342	-0.01152	0.00013	0.31640
30	0.04864	-0.27331	0.05663	0.37507
31	-0.21587	0.50260	-0.17567	-0.06801

include a meaningful interpretation of the factors. Nonetheless, analysis of the factor load of the variables (see Figure 49 below) makes it possible to define a fairly clear factor structure in the algorithm under investigation.

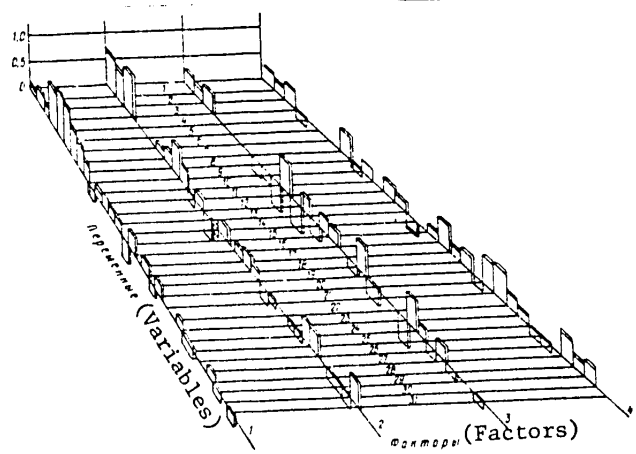


Figure 49. Matrix of Factors of Algorithm of Activity

Thus, factor 1 makes it possible to use variables 9, 10, 12, 15, 16, 18, 20, and 31 to construct the psychophysiological structure of actions characterized by indicators 4-8. Indicator 8 is also closely linked in factor 4 with variables 22, 23, and 28. The high loads of variables 1, 2, and 3 in factor 2 make it possible to identify test indicators 9, 10, 12, 13, 18, 25, 26, and 31 which are closely linked to them.

To analyze the factor structure of an isolated action of the algorithm we selected the indicators shown in Table 8 below.

Table 8. Content of Variables

Number of Indicator	Name of Indicator
1	Threshold of tempo-based tension
2	Addition with switching (productivity)
3	Addition with switching (relative frequency of errors)
4	Entangled lines (productivity)
5	Entangled lines (relative frequency of errors)
6	Arrangement of numbers (productivity)
7	Arrangement of numbers (relative frequency of errors)
8	Landolt rings (productivity)
9	Landolt rings (relative frequency of errors)
10	Compasses (relative frequency of errors)
11	Memory (absolute indicator)
12	Establishing patterns (productivity)
13	Establishing patterns (relative frequency of errors)
14	Number-letter combinations (success coefficient)
15	Time sense (average value)
16	Time of simple reaction to light
17	Time of complex reaction to light
18	KChSM [expansion unknown]
19	Switching off signals (time)

The computations revealed the two basic factors that determine the mutual correlations between variables. Table 9 below gives the factor matrix formed as the result of eight iterative cycles of rotating the axes.

Table 9. Factor Matrix

Number of Variables	Factors 1	Factors 2	Number of Variables	Factors 1	Factors 2
1	0.62838	0.00078	11	0.07397	-0.65085
2	-0.42886	0.31729	12	0.08428	0.17153
3	0.71377	-0.10579	13	0.36680	0.41100
4	-0.31946	0.07397	14	0.43108	-0.30942
5	0.11396	-0.37233	15	-0.34908	0.53504
6	-0.12040	0.38554	16	-0.01872	0.33455
7	0.10308	0.07631	17	0.43463	0.05129
8	0.47270	0.44253	18	0.11085	0.25191
9	0.46560	-0.02331	19	0.39687	0.51533
10	-0.17451	0.73367			

The significant load on indicator of labor activity 19 in factor 2 permits us to identify a comparatively simple and clearly expressed structure of the psychophysiological content of the action, reflected in its links with indicators 10, 11, 13, and 15.

By analyzing the factor matrix of the labor action (see Figure 50 below) and comparing it with the factor matrix of the algorithm (see Figure 49 above), it may be concluded that the dimensionality of the factor space that reflects the pattern of the processes under consideration is reduced as the level of the hierarchy of the organized structure of activity decreases.

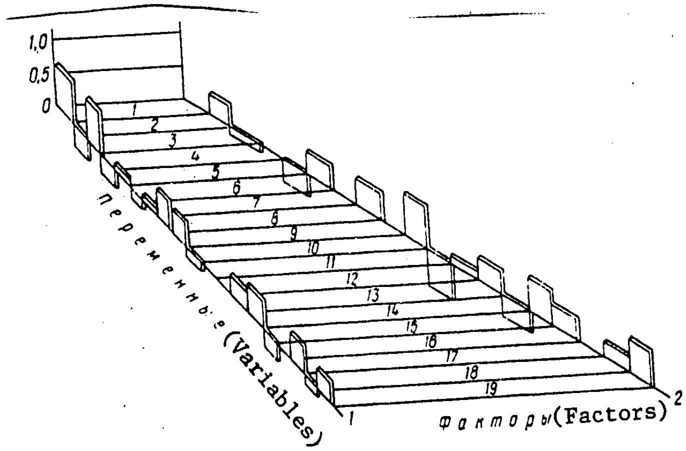


Figure 50. Matrix of Factors of Labor Action.

Investigation of the activity of operators in an ergatic system by factor analysis techniques made it possible to identify the psychophysiological content of labor processes and obtain a qualitative evaluation of the nature of the influence of the principal components of these processes at different levels of their organizational structure.

Development and Investigation of Regression Models of Operator Activity

Qualitative investigation of operator activity, in particular factor analysis of its microstructure, enables us to speak of a stable link between indicators of labor actions and the psychophysiological qualities of the operator, that is, of the existence of inertia in the interrelationships.

Considering the random character of the quantities that reflect individual characteristics of a particular person, it is possible for each labor action to determine a system of random quantities $X_1, X_2, \ldots, X_n$ which are statistically linked to the indicator of success of action D. Then in each test n values $X_1, X_2, \ldots, X$ from the domain of definition of the corresponding random quantity X_i ($i = 1, 2, \ldots, n$) are realized concurrently. Such a set of n values of X_i may be considered the coordinates of realization of random point D* from the domain of definition of indicator D in n-dimensional descartes space. If point D* is connected to the beginning of the coordinates, the set of values X_i($i = 1, 2, \ldots, n$) may be considered as the set of coordinates of projections of realization of random vector OD* on the coordinate axes.

Thus, an n-dimensional system of random quantities is interpreted as a random point in hyperspace or as a random n-dimensional vector and is assigned by a list of its realizations, each of which is defined by a set of n projections of X_1, X_2, ..., X_n to the coordinate axes.

As a mathematical model of the hyperspace of the indicator of the labor action it is possible to use a certain nonrandom function of n random independent variables, the individual characteristics of the operator:

$$D = \varphi(X_1, X_2, \ldots, X_n), \tag{5.25}$$

where ϕ is a certain linear or nonlinear regression function.

A forecast of the results of the action may be obtained by substituting the values of independent variables into the regression equation (5.25) with numerically evaluated parameters, that is, substituting the values of individual operator characteristics identified by testing.

In practice an effort is made to reduce relationship (5.25) to a hyperplane equation

$$D = \sum_{i=1}^{n} a_i X_i + a_0 + \varepsilon_i, \tag{5.26}$$

where a_i is a linear regression coefficient; a_0 is intersection, and, ε_i is errors.

The least squares method was used to obtain linear regression models of the labor actions of an ASU operator performing algorithms. The computations were done with a standard step-by-step multiple regression computer program in FORTRAN [12]. The results of the computations were linear regression equations that express the relationship between time of performance of labor actions and test results. For example, the regression equation for time of signal switching T_1 looks as follows:

$$T_1 = -0,171 \cdot 10^{-1}x_{13} + 0,101 \cdot 10^{-1}x_{15} + 0,003 \cdot 10^{-1}x_{17} + \\ + 2,662x_{18} + 0,937x_{31} + 0,580. \tag{5.27}$$

The numerical indexes for the variables of equation (5.27) correspond to the numbers of the variables given in Table 5 above. The interrelationship of a dependent variable and a number of independent variables is measured in each equation by means of a multiple correlation coefficient.

Analysis of the standard errors of regression coefficients showed that the regression equations are significant. Therefore, the labor actions of the algorithm may be evaluated a priori according to time of error-free performance predicted by means of linear regression models.

3. Situational Physical Models of Operator Activity

Models of Operator Activity Under Time Deficit Conditions

Physical modeling of operator activity as a whole raises substantial difficulties. Therefore, the usual practice is to devise situational models that make it possible to reproduce certain situations that occur in the process of operator activity. Several such models have been developed and studied. They reflect the most typical situations in the work of ASU operators. One of the fundamental features of this activity is the high degree of readiness of operators for emergency actions, that is, actions under conditions of a time deficit.

Analysis of the characteristics of the functioning of complex systems enables us to identify four objective conditions for the occurrence of a time deficit situation [7]:

1. high speed of processes occurring in the control system, in particular because it causes information signals to arrive at a fast pace;

2. shortness of time in which signals are presented;

3. the complexity in multiple elements of the controlled object, which causes a large volume of information to arrive in parallel;

4. unexpectedness of disruptions in the functioning of the controlled object, demanding emergency intervention of the operator.

A time deficit causes the state of tempo-based tension in the operator. This state is characterized by temporary change in the stability of mental processes and vocational work capability [2]. Existing views of the influence of tension on the results of an operator's labor [8] presuppose two basic phases of action by extreme factors. In the initial period of occurrence the tension mobilizes the operator, demanding faster and more accurate work. But as the level of tension and operator activity continues to grow, there comes a time when psychophysiological capabilities preclude a further improvement in the results of labor. The tension value at which its influence becomes negative is called the threshold, and it differs for each individual operator.

A device was developed to make it possible to measure the ongoing value of operator tension as the pace of operator activity increases and to identify the threshold value of tension [13]. The functional diagram of this device is shown in Figure 51 below.

The device works as follows. In the first stage it measures the speed of the human operator in the absence of tension, which is characterized by the average value $\overline{T}_H$ which is necessary to an operator-trainee for error-free execution of the prescribed algorithm without a constraint on working time. To determine $\overline{T}_H$ the key of the switch for speed of information display 7 is set at zero by the performer, then the "Start" button of pulse generator 6 is pushed. This causes the pulse generator to produce a single pulse, which goes to the input of the commutator control circuit 5. This circuit triggers the op code switch 9, which changes the code value at the input of decoder 8. Each of n possible code values at the input of the decoder corresponds to a certain combination of information

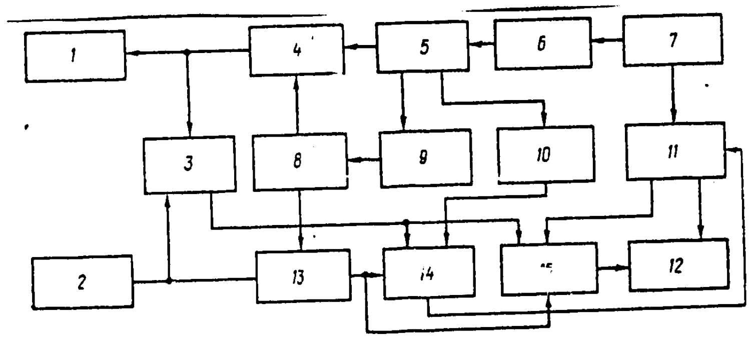


Figure 51. Functional Diagram of the Device To Measure the Threshold of Operator Tension

Key:
(1) Information Display Panel;
(2) Control Console;
(3) Time Counter;
(4) Commutator;
(5) Commutator Control Circuit;
(6) Pulse Generator;
(7) Switch for Speed of Information Display;
(8) Decoder;
(9) Op Code Switch;
(10) Counter for Number of Displays;
(11) Block To Monitor Ongoing Magnitude of Tension;
(12) Register Block;
(13) Error Identification Block;
(14) Unit To Measure Operator Speed;
(15) Block To Identify Threshold Value of Tension.

symbols at its output. This combination assigns one of n algorithms of activity which are equal in difficulty for the operator being tested. Then the commutator control circuit switches on commutator 4 to transmit the information combination from the output of decoder 8 to the information display panel 1.

The subject operator, who has been trained in advance to operate the device, monitors the state of the indicators of panel 1 and, when the transmitted information is displayed, performs operations with control elements 2 (switches and buttons) in a sequence that is determined by the type of incoming signal.

Whether the algorithm is executed correctly is monitored by error identification block 13 which compares the signal arriving from the control console with a standard signal at the second output of the decoder. In case of erroneous actions by the operator block 13 issues a signal to the first input of the unit to measure operator speed 14. Working time is measured by time counter 3 and upon completion of the cycle is transmitted to the second input of the unit to measure operator speed.

This cycle is repeated several times; information on the number of cycles performed goes from the output of number counter 10 to the third input of the unit to measure operator speed. This unit 14 sums the values of the time of error-free performance of algorithms coming from the time counter in the absence of signals at the output of the error identification block, and when the number of error-free cycles performed reaches a given value N, it computes $\overline{T}_H$ by dividing the total time of error-free work by N. The resulting value of $\overline{T}_H$ is transmitted to the memory register of block 11 which monitors the ongoing value of tension, and this is the signal to begin the second stage of work: measuring the threshold of tension of the human operator.

To measure the threshold of operator tension the key of switch 7 for rate of information display is put in the position where the pulse generator produces a sequence of pulses at even intervals that are less than $\overline{T}_H$. Each pulse of the generated sequence changes the setting on the information display panel, requiring that by the time of its arrival the operator have completed the preceding algorithm. Time T_{HM}, available to the operator to execute the algorithm, is limited by the interval between pulses and demand that the test subject increase the speed of performance of operations on the control console. This gives rise to emotional tension.

Each position of switch 7 corresponds to a certain frequency of pulses at the output of generator 6 and a certain time T_{HM}. The value of operator emotional tension in each cycle is computed by block 11 for monitoring the ongoing value of tension. It does this by dividing the value $\overline{T}_H$, which is available in the memory register, by the quantity T_{HM} arriving from the second output of switch 7 for rate of information display.

The investigator increases the frequency of pulses at the output of generator 6 by steadily moving the position of switch 7. This reduces time T_{HM} allocated to the operator to perform the given algorithms correspondingly, and therefore the level of operator emotional tension rises.

The current value of tension of the test subject in each cycle is transmitted to the register block 12 and to the third input of block 15 for identifying the threshold magnitude of tension. Block 15 monitors the timeliness and correctness of performance of the assignment in each cycle according to signals that arrive from the outputs of time counter 3 and error identification block 13 respectively.

The tension value at which the test subject made a mistake or exceeded the allowable working time T_{HM} is considered to be the threshold value and is singled out by block 15 and then recorded in register block 12. The measurement process is repeated several times to improve the precision and authenticity of the determination of the operator's tension threshold.

Using this model the following relationship for average time of the simple sensomotor reaction as a diminishing polynomial function of tension was obtained:

$$Z = 35{,}35\left(\frac{s-1}{M-1}\right)^6 - 103{,}16\left(\frac{s-1}{M-1}\right)^5 + 110{,}94\left(\frac{s-1}{M-1}\right)^4 - 53{,}96\left(\frac{s-1}{M-1}\right)^3 + 11{,}80\left(\frac{s-1}{M-1}\right)^2 - 1{,}30\frac{s-1}{M-1} + 1{,}00 \pm 0{,}14, \qquad (5.28)$$

where Z is average reaction time in seconds; a is the current tension value; and, M is the threshold value of tension (it ranged from 1.5 to 2.5 for the operators tested).

Model of Operator Activity in an Extreme Situation

An important objective accomplished in the process of training ASU operators is evaluation of their emotional stability when working in extreme regimes. One way to obtain such an assessment is to compare the results of operator labor under optimal conditions with the results in an extreme regime. A trainer which uses electrical effects on the skin as a stress factor was developed to make it possible to create extreme conditions of operator activity [14].

Figure 52-53 below presents a functional diagram of the trainer.

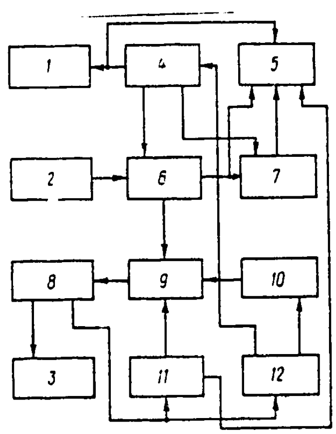


Figure 52-53. Functional Diagram of Control System Operator Trainer.

Key: (1) Display Panel;
(2) Control Panel;
(3) Contact Electrodes;
(4) Program Block;
(5) Register Unit;
(6) Comparison Unit;
(7) Evaluation Unit;
(8) Unit to Measure Skin Electrical Conductivity;
(9) Adaptive Action Block;
(10) Power Supply Block;
(11) Block To Evaluate Emotional Tension;
(12) Protective Monitoring Block.

The trainer works as follows. Program block 4, following one of the possible sequences of symbols, feeds signals to the input of display panel 1. The operator, under instructions, operates according to a strict algorithm and reacts to the signals presented with control actions using the elements of the control console 2.

Signals go from the control console to the comparison unit where they are compared with signals for the "ideal operator," which are transmitted from the output of program block 4. If the incoming signals do not match or the operator is late by a time greater than permissible, an error signal appears at the output of unit 6 and is recorded in evaluation unit 7.

Upon completion of the program, program block 4 feeds a signal to the second input of unit 7, after which the work of the operator is evaluated according to the given criterion. Register unit 5 records the character of the sequence of information signals presented throughout the entire job, the errors made during the job aligned with their places in the algorithm, and the final evaluation at the end of the program.

After several practice cycles of work during which the operator reaches a given level of training, the evaluation of the operator's emotional stability is begun. The process of evaluating emotional stability consists of alternating a given number of work cycles in optimal conditions as described above and cycles under extreme conditions.

To create extreme conditions, contact electrodes 3 are secured to a segment of the subject operator's skin and connected to the adaptive action block 9 through the unit to measure electrical skin conductivity 8. Before the cycle begins an electric current sufficient for unit 8 to measure electrical skin conductivity is passed through the electrodes. The required value of the electrical skin stimulus current used as a stress factor is set up on adaptive action block 9 with due regard for the measured quantity.

During the process of work when an error signal appears at the output of comparison unit 6, block 9 switches off the measuring circuits of unit 8, feeding brief shots of current of a given magnitude to the contact electrodes 3. The sensations of pain that the test subject feels in this case create extreme conditions for activity.

When there is no error signal at the output of comparison unit 6, adaptive action block 9 feeds a weak current through the measuring circuits of unit 8 to the electrodes. At this time a signal that characterizes the magnitude of electrical skin conductivity is taken from the output of unit 8. Block 11 for evaluating emotional tension determines, according to the measured value of conductivity, the degree of change in the functional state of the operator and adjusts the value of the stimulus current so that it matches the assigned magnitude. The value of emotional tension is recorded in register unit 5.

In case one of the units of the action circuit malfunctions and the action current goes beyond the threshold value of danger to the operator's life, the protective monitoring block 12 switches off power supply block 10, giving a warning of this by a standard signal on the front panel of block 4.

4. The Use of Models of Operator Activity for Expert Ergonomic Evaluation of Ergatic Systems

Expert Ergonomic Evaluation: Its Objectives and Methods

Before giving a definition of expert ergonomic evaluation, let us look at the concepts of the expert evaluation and technical expert evaluation.

The expert evaluation ["ekspertiza"] is an investigation of some particular questions by persons who have specialized knowledge in the particular field [15, 16]. Accordingly, the technical expert evaluation is an investigation of a set of technical questions done on invitation or assignment by persons who have specialized scientific knowledge in the fields of engineering being investigated [17].

Such a definition of the expert evaluation emphasizes just one aspect, the methodological (at the expense of the practical). In what follows when we speak of a method or methodology, we will juxtapose these concepts to the concept of "practical activity."

The definition of the expert evaluation that is proposed below has the other shortcoming: it emphasizes the practical aspect of activity at the expense of the methodological.

An ergonomic expert evaluation of a man-machine system is a program of activities aimed at investigating t human factors in different stages of functioning of the systems in order to evaluate how well they are used.

This definition also differs in that it does not have a subject that conducts the evaluation and determines whether the decisions made are correct. This is because the expert evaluation can be done by automated systems using computers, where the human being (subject) takes the part of operator or programmer. Of course, the program is prepared, just as automated complexes are built, by human beings in the process of investigating the structure of the ergonomic expert evaluation.

Investigating the structure of the ergonomic expert evaluation (EEE) is a specific problem in the sense that it must be directed to solving problems that arise with practical EEE. Such an investigation, aimed at solving problems in a particular area of practice, should be considered methodological in relation to the area under consideration.

Thus, the problem of investigating the structure of the EEE should be resolved in the subject of EEE methodology. Because the EEE is also practical activity, we will try to depict it schematically, identifying its elements and structure.

There are many approaches today to a schematic representation of practical activity [4, 18, 19]. The most successful is the diagram presented in work [18]. Figure 54 below shows it with certain modifications. The objective part of the activity includes the initial material of the objective transformation, the

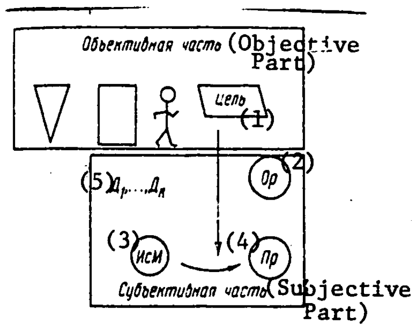


Figure 54. Representation of Practical Activity According to [18].

Key: (1) Goal;
(2) Inplement of Transformation;
(3) Initial Material;
(4) Product;
(5) Actions.

implements of transformation, the actions performed by the human being ($Д_1, \ldots, Д_k$), and the product obtained from transformation of the initial material $П$ (the actions together with the implements form the procedures of the activity). The subjective part of the activity combines the individual, the goal facing the individual, and the internalized means (▽) and capabilities (□) necessary to manipulate the means and construct the procedures of the activity.

This diagram fits that type of practical activity where the individual has a good knowledge of the goal plus the means and capabilities to accomplish it. But the EEE, which is practical activity, cannot be done by the proposed diagram (see Figure 55 below). In this case the expert must be assisted by methodological

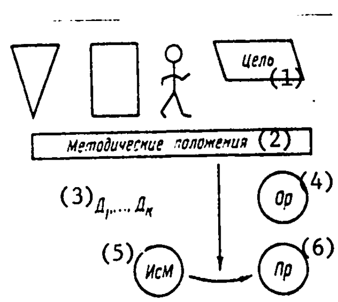


Figure 55. Representation of the Expert Evaluation According to [18].

Key: (1) Goal; (4) Implements;
(2) Methodological Principles; (5) Initial Material;
(3) Actions; (6) Product.

principles formulated by specialists in related fields of knowledge (human factors engineering, ergonomics, and human factors designing) as a plan for the upcoming activity. But this plan can be developed only on the basis of an analysis of procedures already performed. This kind of diagram is shown in Figure 56 below [18].

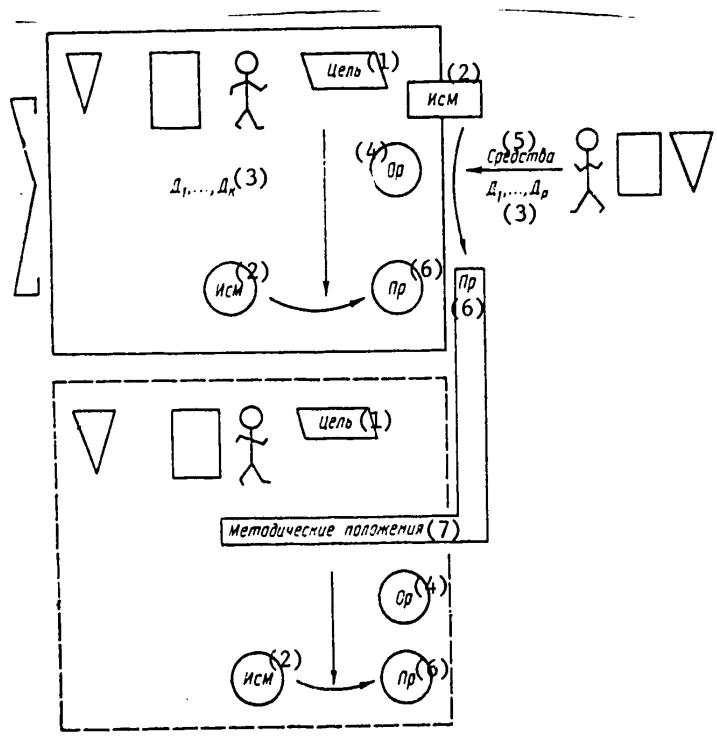


Figure 56. Depiction of Activity To Formulate Methodological Principles (18, p 19).

Key:
(1) Goal;
(2) Initial Materials;
(3) Actions;
(4) Implements;
(5) Means;
(6) Product;
(7) Methodological Principles.

The initial material for a person who is compiling methodological principles (in what follows we will call this individual a specialist, as differentiated from an expert) is the set of distinct actions of the practical activity which were the object of analysis $\left(\sum_{1}^{n}\right)$, while the product of the activity is the methodological principles with which the open-ended practical activity of the EEE is carried on.

Based on this definition of the EEE, the subject of its methodology is an investigation of human factors. By human factors we will mean the variables that influence human characteristics, machine characteristics, and the relations among them [19]. Human factors should be assigned in quantitative terms and specifications for the system (for example, a frequency of five signals a minute). It is not useful, however, to investigate all the human factors separately in order to establish the influence of each one of them on the quality of operation of the system. The reasons are, for one, the difficulty of singling out the influence of any one particular factor on the quality of operation of systems because it by itself may not have a significant impact and, for two, the interdependence of the factors, where change in one factor leads to change in another.

It is essential to study the algorithms of operator activity, because it is precisely the characteristics of the algorithms that ultimately summarize the results of the influence of all human factors on the quality of operation of an ergatic system. Possible exceptions are factors of the external environment and technical-esthetic factors whose influence on indicators of quality of operations is unquestioned, even though it is extremely difficult to find a correlation between them and the algorithm of operator activity.

The methodological principles of conducting the EEE are considered in three aspects.

1. The methodological principles are a means of constructing a new type of activity, the EEE. Their form and content follow from this, and this determines what must be in the methodological principles.

2. The methodological principles are a generalization of knowledge received in the process of human factors designing and evaluation. This generalization reflects the possible content of the methodological principles.

3. Methodological principles are a product of methodological activity. Thus, knowing the features of the methodological principles considered in these three aspects, it is possible to define the type of the corresponding methodological principles.

As can be seen from the diagram given in Figure 56 (above), the methodological principles must contain references to all the elements of the activity facing the expert:

- type and nature of results of EEE;

- type and nature of initial material for transformation;

- implements and means essential for the transformation;

- nature of individual actions which must be performed, and their order.

The initial material for transformation does not remain constant during the process of EEE. This is because the EEE in the process of functioning passes through such different stages as design, production, and operations. Depending on the stage the initial material will be, respectively, the design of the ergatic system, an experimental or series-produced prototype of the machine undergoing testing in factory conditions, and the ergatic system in operation.

A change in the initial material for transformation makes it necessary to use other means and to carry out actions corresponding to them, in other words, to change the entire objective part of the EEE.

It follows from this that the EEE must be done in each stage of functioning of the ergatic system, and human factors must be investigated and evaluated with due regard for the particular features of this stage.

In the design stage the initial material of the EEE is the design of the ergatic system, and the product is the ergonomic evaluation, which is a prognostic evaluation of successful functioning of the ergatic system in operation. When we consider also the complexity and multifaceted nature of the human factors subject to investigation, we must recognize that the only possible way to predict the work of systems is simulation modeling.

A simulation problem prepared for automatic processing can be repeated a number of times with different alternatives of workload, resources, decision-making logic, service personnel, machine speed, levels of automation, and the like. This kind of model can make it easier to produce a preliminary evaluation of the ergatic system and to identify the most strained aspects, related to overloading equipment or personnel.

Returning to the diagram of the EEE (see Figure 56 above), it should be specified that the implement of the expert in the design stage will be a computer, and the actions will be analysis of human factors in the design of the ergatic system, programming the data received, and feeding them to the computer.

Of course, one expert alone cannot handle such diverse tasks. Therefore, it is wise to have a group of at least two persons: an expert in human factors and a programming engineer. In this case the programming engineer will be, in a sense, the "implement" of the human factors expert (see Figure 57 below). The form and content of the methodological principles follow from this. They should consist of two parts: methodological principles for analysis of the human factors, and methodological principles for programming and feeding data to the computer.

The activities of the specialist also vary. When working out the methodological principles for programming and feeding data to the computer, the specialist should at the same time develop the rules of functioning of the system in the form of a computer program consisting of encoded instructions.

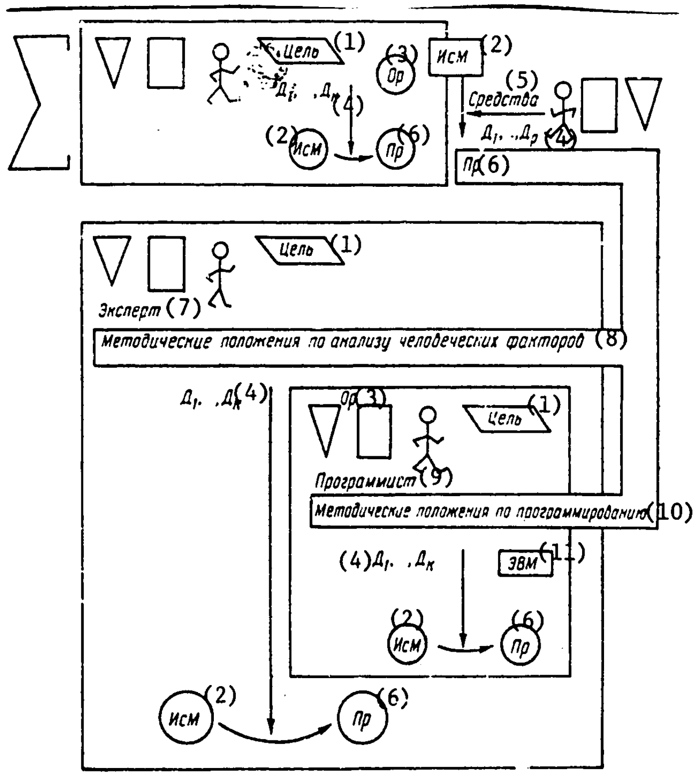


Figure 57. Diagram of Activities To Formulate Methodological Principles and Conduct the EEE.

Key:
(1) Goal;
(2) Initial Material;
(3) Implement;
(4) Actions;
(5) Means;
(6) Product;
(7) Expert;
(8) Methodological Principles for Analysis of Human Factors;
(9) Programmer;
(10) Methodological Principles for Programming;
(11) Computer.

The initial material in the stages of production and operation differs from the initial material in the design stage in the same way as the design of any system differs from an experimental model or a system that has been tested in operation. Therefore, changes occur in the implements of transformation, actions, and, of course, methodological consequences. But the initial material in the design stage also has features in common with the initial material in the stages of production and operations.

Therefore, many of the methodological principles adopted in the design stage must be kept in the stages of production and operations. In the succeeding stages the methodological principles must be supplemented as the initial material changes. In the design stage, for example, an experimental model or dummy may appear, which makes it possible to investigate human factors and conditions that approximate the conditions of system operations. Moreover, this offers an opportunity to compare the results of modeling with data on the functioning of a real system and to refine the simulation model. The same thing is true of the stage of operating an ergatic system.

Investigation of human factors in different stages of the functioning of an ergatic system is done to evaluate the quality of system operations. Thus, these indicators should be reflected in the methodological principles as norms or requirements.

The following indicators are used to evaluate the quality of operation of an ergatic system:

1. the readiness coefficient $K_r = K(F_ч, F_м)$, that is, the probability that the ergatic system will be in working condition at the moment that an instruction to perform work arrives ($F_ч$ is human factors, and $F_м$ is machine factors);

2. the probability of trouble-free work by the ergatic system $T = P(F_ч, F_м$, and $\tau)$;

3. the indicator of timely performance of the task $T = T(F_ч, F_м)$.

The job of the specialist in formulating methodological principles is to identify that part of the indicator of quality of system operations that depends on human factors. For example, on the condition that $F_ч$ and $F_м$ are independent, we may write $K_r = K_r(F_ч)K_r(F_м)$, where $K_r(F_ч)$ is the part of K_r that depends on human factors and $K_r(F_м)$ is the part that does not depend on them.

Devising a General-Purpose Ergonomic Model of an Ergatic System

In different stages of functioning of the ergatic system, the EEE has distinctive features related to the special characteristics of the simulation model of the system.

In the design stage the simulation model of the ergatic system, formulated by a specialist, is the implement of expert E_1 at the design bureau or scientific research institute (see Figure 58 below). Section 2 dealt with synthesizing such models. The type of model depends on the type of operator activity. The reader must not be confused by the equating of the concepts of "simulation model" of operator activity and of an ergatic system. Practically speaking, they perform the same functions.

Expert E_1, conducting the EEE in the design stage, receives a preliminary evaluation of the ergatic system that helps to refine the design. Moreover, the model

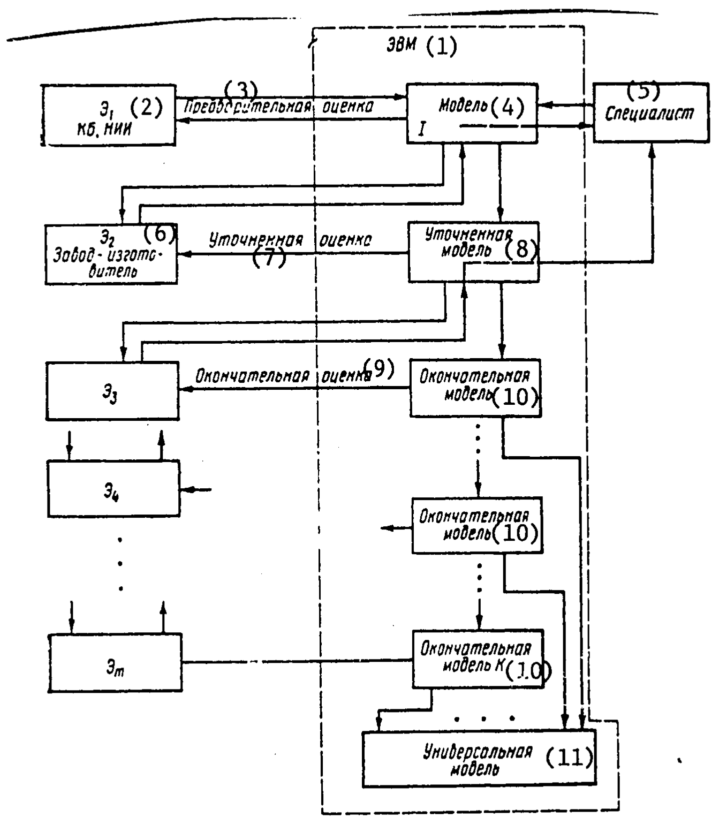


Figure 58. Diagram of Conduct of the Ergonomic Expert Evaluation.

Key:
- (1) Computer;
- (2) E_1 [Expert No 1], design bureau, scientific research institute;
- (3) Preliminary Evaluation;
- (4) Model;
- (5) Specialist;
- (6) Manufacturing Plant;
- (7) Refined Evaluation;
- (8) Refined Model;
- (9) Final Evaluation;
- (10) Final Model;
- (11) General-Purpose Model.

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serves as a foundation for expert E_2 at the manufacturing plant. This expert, using additional means (dummy, experimental prototype, and situational models), receives data for making the simulation model more precise.

Because it is a specialist who is directly involved in writing the machine program that determines the logic and sequence of operations to store information, process it, and print it out, the specialist also refines the model, comparing modeling results with data on the functioning on the experimental prototype. Data on the refined model goes to expert E_2 in the form of a refined evaluation of the ergatic system.

The refined model serves, in turn, as the foundation for expert E_3, who uses data accumulated in the process of operating the ergatic system to obtain results for the final refinement of the model. These data go to a specialist who compares modeling results with results of the functioning of the real system and does the final refinement of the model.

Data on the final model go to expert E_3 in the form of a final evaluation of the ergatic system. It should be considered that there is no reason in principle why one expert could not work instead of three (E_1, E_2, and E_3) or, by contrast, there could be a fourth expert E_o who coordinates the work of the others.

The work of the experts (E_4, ..., E_m) to investigate the human factors in other ergatic systems goes ahead parallel with expert evaluation of the first ergatic system. In this case the specialist or specialists formulate the final models (Π, ..., K).

During the investigation of a system of some one class in a certain stage of development of the final model, as they are enlarged in breadth by increasing the number of components being modeled and in depth by differentiation of operations, breaking them down into components, and instituting new links and factors which were neglected earlier, the models acquire the characteristic of commonality. A general-purpose ergonomic model which provides a great savings of computer resources during the process of the EEE can be formulated on the basis of these models.

In addition, in the stage of universality the model acquires a new quality and becomes a convenient means of accumulating information when essential data are included in the algorithm of computer functioning.

The general-purpose ergonomic model constructed on the basis of the models described in sections 2 and 3 was tested experimentally and demonstrated good capabilities for conducting expert ergonomic evaluations.

5. The Use of Models of Operator Activity To Predict the Professional Success of ASU Operators

The Problem of Predicting Professional Success of Operators

Of course, the decision to admit people to training and practical activity in the operation of ASU's is made on the basis of an evaluation of their academic and vocational progress before undertaking the actual work of system operators. Therefore, it can only be obtained by prediction. The initial data here are descriptions of the individual characteristics of the operator, and the final result is the expected efficiency of their manifestation in the process of practical work within the system.

The task of predicting the professional success of an operator can be formulated in general form as follows. Suppose we have the results of activity by subject j in regime k of testing his or her individual characteristics:

$$\overline{D_j^k = f[\delta_j^k(t), v_k \in V]}, \quad t = t_0, \tag{5.29}$$

where $\delta_j^k(t)$ is the vector of descriptions of the activity of subject a in regime k; $v_k \in V$ is the vector of descriptions of the factor structure of regime of activity k; and, t_0 is the current moment in time.

It is necessary to determine this functional:

$$\overline{u(t) \in u_{\text{доп}}} \tag{5.30}$$

($u_{\text{доп}}$ here is the function of the space of permissible transformations), and with this functional it becomes feasible to make the transition to an a priori evaluation of the results of practical activity of subject j in the process of operating a particular ASU:

$$D_j^k \xrightarrow{u} \overline{D_j^* = f^*[\delta_j^v(t), r \in R]}, \quad t \in T_{\text{пр}}, \tag{5.31}$$

where $\delta_j^v(t)$ is the vector of descriptions of the practical activity of subject j in the process of operating the ASU for the most informative level of the organized structure of labor processes v; $r \in R$ is the vector of descriptions of the factor structure of the processes of operating the ASU; and, $T_{\pi p}$ is the confidence limit of prediction time such that the error of the prediction is minimized, in other words

$$|\overline{D_j^* - \hat{D}_j}| \to \min, \tag{5.32}$$

where $\hat{D}_j$ is the a posteriori evaluation of the vector of results of practical activity by subject j in the ASU being operated.

Development of Methods of Predicting the Professional Success of Operators

Mathematical models of multiple regression are often used for the desired functional u(t). These models consider the domain of change in the parameters of the subject's professional success in the form of a hyperplane in the n-dimensional Cartesian space of the individual characteristics (factors) of the person X_1, X_2, ..., X_n. But investigations that have been made have shown that the dimensionality of factor space increases sharply in the case of complex multi-algorithm operator activity; moreover, numerous factors have different impacts on the results of execution of the same algorithm. For these reasons regression models become insensitive to the results of operator activity as a whole.

The most informative level of the organizational structure of activity for the application of regression models is that of distinct labor actions of the algorithm (see section 2) which have a comparatively simple, easily differentiated factor structure. We know from work [8] that when an extreme situation occurs the results of the operator's labor actions undergo distorting changes that are the result of the individual characteristics of the person's stress stability. Investigation and evaluation of these characteristics of the subject is done using situational physical models that recreate the extreme conditions of labor (see section 3). But the complexity of the interrelationships among particular actions in the labor process, even taking into account the patterns of distortion of their results, makes it impossible to obtain characteristics of the operator's execution of the algorithm and activity as a whole analytically.

In this case it is possible to propose a method of predicting the professional success of operators that combines the results of the application of mathematical regression and situational physical models on the basis of simulation modeling of operator activity. The digital simulation model takes account of the statistical links among labor actions, the laws of distribution of random quantities, and the psychosocial and other factors of activity. It makes it possible to carry out the transition from more informative levels of the organizational structure of labor processes to forecasting their integrated results.

The functional for predicting the results of practical activity by subject j in performance of algorithm m is described by the iterative procedure

$$\overline{u(t): D^*_{mj}} = \delta'_{i-1,j} + \delta'_{i,j}[F_i(X^n_j)\,Z\{\delta'_{i-1,j}, Q_i(t), M_j\} + S_i(\bar{\sigma}_i, \xi_i)], \quad i \;\forall I_m, \quad \xi_i \in [0, 1], \tag{5.33}$$

where $F_i(X^n_j)$ is the regression function of the results of action i depending on the characteristics of n-dimensional vector X^n_j of the individual characteristics of subject j; $Z\{\delta'_{i-1j}, Q_i(t), M_j\}$ is the function of distortion of the results of action i depending on the vector of results of the preceding action $\delta'_{i-1,j}$, the vector of characteristics of the situation $Q_i(t)$, and the vector of individual characteristics M , which describe the stress stability of subject j; S $(\bar{\sigma}_i, \xi)$ is the function that considers the mean quadratic deviation of the results of action $\bar{\sigma}_i$ and the law of distribution of results that is reflected by pseudorandom quantity ξ_i; and I_m is the set of labor actions included in algorithm A_m.

The multidimensional vector $\bar{D}^*_{mj}$ of the parameters of the labor process is formed by running a large number of iterative procedures with data that describe the individual characteristics and stressability of subject j. This vector is statistically reliable material for an a priori evaluation of the professional success of the test subject in performance of algorithms of activity m. With a known, high convergence of the results of prediction with data from practical activity, the vector $\bar{D}^*_{mj}$ can be evaluated on the basis of standards and criteria that evaluate operator activity in the process of operating an ASU. But as a rule the simulation model produces a certain shift in the values of the parameters being predicted. In this case, it is possible to use the mathematical apparatus of discriminant analysis [20], which assigns boundary hyperplanes in the q-dimensional space of output parameters of the model under investigation in the form of linear classification functions

$$k_m(\bar{D}) = B'_q \bar{D}^*_m + B_0, \tag{5.34}$$

where k_m is a parameter of the classification group of individuals with a certain definite level of professional success in performance of algorithm of activity m; B'_q is the vector of coefficients of discriminant functions; and, B_0 is the vector of intersections of the discriminant functions.

Identification of the classification function with the maximum value for parameter $K_m(D)$ makes it possible to assign the test subject j according to professional success in performance of algorithm m to the group of operators corresponding to the number of the given function with a probability of

$$p_a = \frac{1}{\sum_{l=1}^{N} e^{(f_l - f_a)}}, \tag{5.35}$$

where f_l is the value of discriminant function l; f_a is the value of the largest discriminant function; and, N is the number of discriminant classification functions.

The final evaluation of the test subject's professional success in relation to the activity as a whole is determined from the expression

$$Y_j = \alpha_1 \frac{1}{a_{1j}} + \alpha_2 \frac{1}{a_{2j}} + \cdots + \alpha_m \frac{1}{a_{mj}}, \tag{5.36}$$

where α_m is a coefficient that considers the frequency and relative importance of performance of algorithm m in the cycle of operator activity.

Experimental investigation of the proposed technique for operator activity, including the three basic algorithms, showed that it has significant advantages over well-known methods, in particular when compared to the method that uses regression models of activity as a whole.

Chapter 6. Methods of Processing Physiological Data on the State of the Human Operator in Specialized Technical Units.

In most contemporary technical control systems no matter what the level of automation is, the human being continues to have the basic, decisive organizational and monitoring role in the control process.

Raising requirements for the reliability of control systems led to the development of automatic units to monitor and diagnose the state of technical control systems [1]. Therefore, it is entirely natural that there be interest in the questions of building automated systems to diagnose the state of the human operator during various types of activity.

The problem of diagnosing the state of the operator during labor activity involves establishing the degree of ongoing correspondence between the operator's capabilities, personal characteristics, and state of health and the structure of the production activity and suitability of the operator to perform the assigned task.

Three basic scientific problems are resolved during the development of systems to diagnose the state of the operator:

1. search for and study of characteristics of the state of the operator;

2. development of methods and principles of diagnosing operator states;

3. development of principles for constructing technical diagnosis systems.

The choice of the method of technical diagnosis of the state of the operator is determined by the psychological structure of the professional activity and the possibility of employing the method by technical means under the concrete conditions. The most widespread techniques of diagnosing the state of the operator at the present time use these indicators:

1. parameters of labor activity;

2. results of work on modeling installations;

3. psychological parameters;

4. data from physiological measurements.

Each of these methods has strengths and weaknesses, and no one of them can be given preference. It appears that only an intelligent combination of all these methods will result in the most complete determination of the capabilities and state of the human operator. Despite the difficulties of obtaining physiological data and identifying them with the psychological state and the necessity of correlating mental functions with the state of acquired skills, however, the methods of evaluating the operator's state based on physiological data are attracting a growing number of investigators because of the possibility of continuously monitoring the process of labor activity.

It is extremely necessary to evaluate the ongoing state of the operator during the preparatory period and in the process of labor activity in many cases both to monitor the operator's work capability and for the purpose of timely intervention in the process of controlling the object where the state of the operator abruptly worsens owing to critical overloads or other causes. The problem of increasing flight safety for aircraft, reducing the accident rate in railroad and motor vehicle and transportation, raising the quality of industrial processes, and the like, that is, those problems in which one person combines all three types of operator activity (observer, manager, and performer) during the control process and overloads or even brief disruptions of the activity of the human operator may lead not only to failure to perform the assigned task but to very grave consequences, cannot be resolved at the present time without building technical systems for automatically monitoring the ongoing psychophysiological state of the operator.

Let us consider certain questions of diagnosing the state of the operator during preparation for performance of the assignment and in the process of labor activity (or when working on modeling installations) based on data from physiological measurements. In particular, let us briefly consider the questions of selecting informative physiological parameters and characteristics for monitoring the state of the operator, certain questions of constructing specialized technical monitoring systems, and techniques for processing and classifying electrical physiological data in such systems.

1. Brief Analysis of the Physiological Parameters and Characteristics of the State of a Person

The possibility of an operator's performing assigned tasks is closely related to the state of the operator's health and mental functions. A set of mental processes and definite relations among the constituent parts correspond to each action by the operator. If even one of the constituent parts is outside tolerances the quality of performance of functions by the operator suffers, and in some cases this may even lead to failure to perform the task.

In its turn, the mental state of the operator depends on the state of the nervous system and the state of the various physiological systems. Disruption of the activity of these systems can lead to impairment of the composition and area of normal functioning of the set of mental functions.

The close interrelationship and interdependence of the human mental and physiological states permits conclusions about a person's psychophysiological state to be drawn on the basis of an analysis of the set of physiological parameters [3, 4].

At the present time, of course, it is difficult to assert a complete correspondence between the physiological and psychological states. All the recordable physiological parameters are generalized parameters of complex interrelated physiological systems and describe integrated indicators of mental activity. But research in recent years has established many stable correlations between the state of the operator's physiological systems and mental activity [4, 5, 6].

The principal difficulty of using electrical physiological data for purposes of diagnosing the state of the operator lies in the complexity of mathematical processing and interpretation of the resulting data. The primary indicants of operator activity are often used as criteria to evaluate the operator's labor activity. But this labor activity is determined by the state of mental processes, which are already secondary indicants. Finally, the physiological parameters that determine the state of the mental functions are tertiary indicants of the labor process. Therefore, when determining the state of operators and their ability to perform assigned tasks on the basis of physiological parameters, one must have an adequately complete idea of the interdependence of all processes.

When monitoring the state of an operator based on physiological data, the initial information on the state of the person is represented in the form of a set of components of electrical signals — various medical electrograms that describe the physiological state of the systems of the entire organism [3, 4, 5].

Table 10 below lists the most important physiological parameters that carry information on the state of the organism.

Table 10. List of the Most Important Physiological Parameters

Parameters	Frequency Band, Hz	Amplitude Range, mv
	Electrophysiological Parameters	
Electrocardiogram	0.2-100	0.1 -5
Electroencephalogram	1 -100	0.01-0.5
Electromyogram	10 -500	0.01-5
Electroretinogram	0.3-100	0.1 -1
Electrooculogram	0.5- 15	0.01-3
Skin Potentials	0 - 0.5	0.1 -10
Electrical Conductivity of Skin*	0 - 0.5	
Rheocardiogram*	0.1-100	

[Table 10 continued next page]

[Table 10 continued]

Parameters	Frequency Band, Hz	Amplitude Range, mv
Nonelectrophysiological Parameters		
Body Temperature	0 -1	Depending on the sensor
Pneumogram of the Thorax	0 -50	
Sphygmogram	0.1-20	
Frequency of Breathing	0.1-2	
Arterial Tachooscillogram	0.2-20	
Arterial Pressure	10 -150	
Frequency of Heart Contractions	0.5-5	
Plethysmogram	0 -5	
Phonocardiogram	16 -500	
Kinetogram	5 -50	
Spirogram	0 -100	
Voice and Speech of Subject	50 -3000	

[Note: Asterisk indicates that amplitude range depends on measurement schemes; for nonelectrophysiological parameters amplitude range depends on the sensor.]

Changes take place in the entire organism, that is, in all systems and organs, during measurement of the psychophysiological state of a person. But the degree of change in physiological functions differs significantly. There is a great difference in the reaction time of physiological indicators to an influence. Some physiological indicators such as arterial pressure, frequency of breathing, and pulse rate react immediately to overloads. The change in other parameters such as composition of the blood and morphological change in the blood vessels is protracted in nature, and sometimes results only from the repeated effect of overloads [5, 6].

Therefore, all physiological functions are conventionally broken into three groups according to the degree of reflection of functional changes that take place during a change in the state of the organism:

1. functions that have marked inertia (changes in the internal environment of the organism, the content of metabolites in the blood, body temperature, and the like);

2. functions that have slight inertia (pulse rate, frequency of breathing, and the like);

3. functions that reveal changes only concurrently with change in the state of the organism (muscle biocurrents — the EMG, brain biocurrents — the EEG, and others).

The informative quality of a physiological parameter is a result above all of a high degree of correlation between change in the psychophysiological state of a person and change in the physiological indicator; a second factor is the speed with which the particular parameter reacts to the disturbing influence. The latter is quite important for predicting the state of an operator.

The basic requirements for selection of recordable physiological parameters for technical systems to monitor state are conditioned by the requirements made of the element of the systems being analyzed, and include the following:

- an adequate group of informative physiological parameters to insure reliability in the evaluation of state;
- automatism in taking the physiological parameters;
- reliability in taking and recording the physiological parameters, that is, reliability of the sensors;
- weight and dimensions of biosensors, recording devices, and convertors;
- continuity of recording the physiological parameter;
- possibility of rapid decoding of physiological data to enable the diagnostic system to work in real time;
- ability of the operator to wear the biosensors without detriment to the work process.

It should be noted that when the state of an operator is diagnosed by electrograms taken from the operator, the discomfort associated with the presence of different sensors on the body of the operator has a certain significance. Studies have shown that significant numbers of ostial follicules on the face and neck, dermatitis, and the like are sometimes observed in persons who have worn headphones and sensors for physiological and clinical equipment for several days [7]. But an intensive search is now underway for new parameters and new methods of recording and amplifying physiological signals and engineers are working to develop new types of sensors and methods of securing them that reduce the level of discomfort and harmful consequences and raise the level of reliability of the information recorded [8, 9].

In light of the requirements presented above for the selection of physiological parameters, let us consider some of them with due regard for the possibility of using them as a source of physiological information to monitor the state of an operator in the process of immediate preparation for performance of the assignment and during work on modeling installations or in labor activity itself.

The electrocardiogram and its various modifications reliably reflect the work of the heart and are the most objective indicator of changes in heart work. The EKG's of a person taken on three leads during the action of external factors that differ in magnitude reveal substantial changes [6].

Fairly broad sets of signs have been obtained as a result of extended medical practice with the EKG. These signs are constructed by identifying in the medical curve particular characteristics of states (waves, deflections, and troughs) and their numerical measurements. Thus, in the EKG we identify the P, Q, R, and T waves, describe characteristics of their form, measure certain distinctive dimensions, and so on. Work underway recently to automate analysis of the amplitude and form of EKG waves is making this parameter one of the highly informative physiological indicators for systems to diagnose the state of an operator.

The sphygmogram has a complex structure and describes the state of a person's cardiovascular system quite completely. There is a strong correlation between this curve and dynamic phenomena occurring in the heart and arterial system during the cardiac cycle. Such important characteristics of blood pressure as the following can be determined by the sphygmogram curve:

a. final diastolic pressure, corresponding to the moment of transition from one cardiac cycle to the next;

b. maximum systolic pressure;

c. dicrotic wave (censor).

The importance of direct measurement of arterial pressure for evaluating the state of a person has been recognized for several decades now. In recent times small, highly sensitive sensors for recording the sphygmogram have appeared. They help increase the efficiency of monitoring the state of the operator [10].

Identification of artifacts plays an important part in monitoring blood pressure. The most strongly manifested artifacts in the sphygmogram are those evoked by movements of the test subject, interference from the electrical circuit, and the potentials of the skeletal muscles. Because they are unpredictable, sphygmogram investigation and measurement of its characteristic quantities is done for a period of time corresponding to several cardiac cycles.

Arterial pressure is one of the most indicative physiological parameters for evaluating the state of a person in general, and for the syncopic state (faintness) in particular. Systolic bronchial arterial pressure is cut almost in half, from 120 to 70 mm mercury column during faintness. This drop in blood pressure reflects well the organism's transition to the syncopic state. Abrupt changes in blood pressure also occur with the action of various accelerators, and there are differences in the effect of differently directed accelerations [6].

All of the proposed methods of measuring arterial pressure are based on periodicity of measurement (the shortest cycle is 40 seconds). In other words, they do not provide continuous information and for this reason are ill-suited for use in systems for automated diagnosis of the state of an operator. From a medical point of view these techniques also have a significant shortcoming, namely that repeated constrictions of an artery and the adjacent blood vessels causes stagnation in the veins and disruption of blood supply, which itself becomes the reason for an aggravation of the state of the organism. Therefore, the curve of arterial pressure, the spyghmogram, is the technique of greatest practical interest for systems to diagnose the state of an operator.

Frequency of breathing is a parameter that reacts quickly to a change in the state of an operator. Experiments with graphic recording of respiration (the pneumogram) showed that when accelerations increased a slowdown of breathing is observed, and with significant overloads respiratory waves may be erased altogether. Faintness and sleep are always characterized by a decrease in frequency of breathing [6]. The frequency of breathing may be one of the basic physiological indicators for systems to diagnose the operator in the process of labor activity. Good pneumogram sensors have been developed which are reliably secured and do not disrupt the work process. Information is recorded continuously and automatically.

The electrogalvanic reflex — the galvanic reaction of the skin (change in the electrical resistance of the skin) to a change in the state of the person — is very sensitive to a change in the state of the person. The states of sleep, work, and stress can be distinguished by the magnitude of the electrogalvanic reflex. Good skin galvanic reaction sensors have been developed.

The pulse rate correlates quite clearly with the state of a person [6]. Many studies on the effect of accelerations and overloads on frequency of heart contractions have shown that when the magnitude of an existing acceleration or overload increases the pulse rate also increases, reaching a maximum of 100 beats a minute. The pulse rate drops sharply when the syncopic state is reached, some times going to zero because of a complete, temporary heart stoppage. Information on the pulse rate may be obtained using sensors for other physiological parameters such as the EKG (in order not to overload a person with sensors) or by special pulse rate sensors.

The electrooculogram records eye movement reactions. The technique for taking readings has been quite well developed. Because movements of the eyeballs slow down when fatigue develops and sleep approaches, and stop when a person loses consciousness, changes in the electrooculogram have a fair amount of information about the state of the operator.

The electromyogram records the electrical signals of the muscles and reflects the functional state of the muscular apparatus. It has been established that the level of muscular tension is higher when the mental work of the operator is more complex and intensive. When the person loses consciousness muscle tone is usually relaxed, muscular hypotonia [11]. During faintness, however, changes in the electromyogram are ambiguous. According to clinical statistics 13 percent of all cases of faintness are accompanied by a convulsive state of the muscles, even though the beginning of changes in the electromyogram is the same in all cases of faintness, including convulsive ones: relaxation of the muscles. A good methodology for recording muscle biocurrents has been developed, as have good electromyogram sensors [11]. The informative value of the electromyogram as part of the set of physiological parameters is quite high.

The electroencephalogram records electrical brain signals. They are the most direct indicators of the work and state of the brain cells. Because the EEG is the summary signal of the activity of numerous nerve elements, it is very difficult to decipher. It is considered possible to use three types of EEG's: desynchronized, transitional, and synchronized with an external stimulus. These types of EEG's can serve as the criterion of the functional state of the central nervous system [12].

Considering the possibility of continuous recording of the EEG, the fairly well developed system of sensors and convenience of securing them, and techniques now in existence are under development to analyze and decipher the EEG, it may be considered an informative parameter for diagnostic systems on the condition that the set of other physiological parameters is taken into account.

Each of the above-listed electrograms gives certain information about the state of the organism and the central nervous system. But this information is still inadequate to judge their significance and the superiority of one parameter to another during the selection of parameters. We know that if certain parameters are not significant with respect to the criterion of evaluation chosen, this does not mean that all parameters or the group of them cannot be significant. A final evaluation of their information value can only be obtained in the process of studying the diagnostic system using appropriate algorithms that make it possible to disclose the influence of each parameter on the result of diagnosis.

The above-listed parameters are considered most appropriate for use in systems of automatic diagnosis in the sense that they react most noticeably and quickly to changes in the psychophysiological state of the operator and recording them is most convenient and, to some degree, has been solved.

During analysis of electrograms a distinction is made between direct signs of the shape of a curve and indirect ones [4]. Direct signs have resulted from extended medical experience and are based on identification and description of typical characteristics of the curve (wave, deflections, and troughs), their numerical measurements, and certain relationships among them.

These signs are good because they make it possible to alternate the process of assembling the techniques found by medical scientists for describing them. But it is very difficult to consider this approach to the analysis of electrogram promising. This description is not complete and economical; the signs themselves do not always permit precise statement and formal description. Even for the EKG, the best-studied curve, these signs do not carry all the useful information that the record itself has. We have learned that complete systems of EKG signs permit diagnosis with greater reliability than is possible with the use of direct signs.

Work [13] gives a fairly detailed review of methods of analyzing and classifying direct signs in technical diagnosis systems.

From the standpoint of adequate information value and economy of coding, indirect signs of signals are extremely interesting. Among them we may identify some expressive and easily fixed part of the shape of the signal (for example, its extreme projections, the slant of the front or back, the perimeter or median line, clearly marked asymmetry, and so on) or the result of interaction between the signal and another known signal. At first glance indirect signs do not seem informative enough. But we have learned that these signs of electrograms obtained by condensing information have high information value and low redundancy [4, 5, 10, 13, 14]. In what follows, therefore, we will consider methods of processing electrograms that reflect the state of the physiological system in the shape of the curve.

2. Methods of Processing Electrograms in Technical Diagnosis Systems

Automation of the process of diagnosing the state of the operator by physiological parameters promotes a significant improvement in the efficiency of this process. This is particularly true of automating analysis of the various medical electrograms recorded from the operator.

Automating the process of diagnosing the state of an operator by physiological parameters became possible thanks to the development of methods of formal description and encoding of electrograms and to the development of specialized and general-purpose computers capable not only of performing the tasks given to them but also of searching for ways to solve complex "intellectual" problems: image recognition [13].

At the present time the tasks of image recognition are formulated in deterministic and statistical forms, and the instruction of automatic image recognition systems divides into instruction with a teacher and without one [15].

The statistical approaches are most useful in the stage of analyzing the information value of signs and establishing the degree of correlation between mental and physiological processes and medical diagnosis and diagnosing the state of the operator by psychological parameters and the parameters of labor activity [14].

The deterministic techniques are most suitable for analysis and classification of electrograms that carry information on the state of a physiological system in the form of a curve (EKG, sphygmogram, and electrooculogram), frequency of oscillation (pulse rate recording, frequency of breathing), or statistical characteristics of the process (EEG, electromyogram, and KGE [expansion unknown]. Deterministic formulation of the problem of recognition of electrograms involved a preliminary determination of the areas of distribution of the signs that characterize different states of the operator based on statistical samples of electrograms and the instructions of the teacher, and then distinguishing curves offered that are not part of the teaching sample, without the teacher's instructions.

Digital computers are widely used under hospital conditions to analyze electrograms. But the techniques of sequential analysis of electrograms based on the use of digital computers are complicated by the need for additional consideration of the concrete conditions of performing the task, the presence of numerous artifacts, the requirements of work on a real time scale, and limitations related to the finite memory volume and cost of the equipment [10, 13].

One of the causes of these limitations is the fact that before electrograms can be analyzed continuously by computer they must be coded. When this type of information is coded on the basis of the Kotel'nikov-Shannon theorem, the number of signs may reach several thousand and it becomes difficult to construct a classification algorithm using them. When several continuous curves are processed synchronously the problem of memory arises, even for contemporary computers.

Analysis of initial physiological information shows that it cannot always be fed directly to the computer because of the limited sensitivity of the input units and the presence of interference. Table 10 above shows that the frequency spectrum of human physiological parameters ranges from zero frequency to frequencies on the order of several kilohertz, and the large majority of these parameters are in the infrasound frequency range. Analysis of the amplitude of electrograms is complicated, however, by the nature of the signal being received. The dual amplitude of most signals recorded from a human operator is in the range 0.01-10 mv, but it is most often hundreds of microvolts. The complex shape of the curve and its lack of periodicity make it difficult to receive a high initial signal/noise ratio. The main problem here in the process of recording electrograms is the appearance of undesired interference in the output signal from the electrical circuit, bias currents in the wires and on the body of the operator, and so on [16, 17, 18]. Appropriate compensation techniques must be used to reduce them.

These and many other factors necessitate some preliminary processing of initial data to amplify and filter it and reduce its volume as much as possible.

All of these factors stimulate the development and construction of specialized units for processing and analyzing electrograms that are simple and convenient to use and permit diagnosis during the process of the operator's labor activity or in the stage of preparation for it.

In specialized devices designed to analyze particular electrograms, the state of the operator may be diagnosed by analyzing its amplitude components [13, 14, 17]. In this case the estimates of the values of particular segments of the curve that have been found are compared with standard values stored in the long-term memory unit. The results of the comparison are used to make the diagnosis of the state of the operator.

Diagnosis according to the results of analysis of amplitude components is one of the particular cases of the more general technique based on the use of the observed dependence of the shape of the electrogram curve on the physiological state of the operator. In most practical cases the shape of the electrogram curve (EKG, sphygmogram, electrooculogram, and the like) carries fuller information about the state of the operator than the amplitudes of its components. Therefore, diagnosis not only by amplitude components but also by analysis of the shape of the curve is the most reliable technique.

The only known devices for analyzing the shape of particular electrograms are units to analyze the EKG [8, 18]. But EKG analysis in this case is not done on a real time scale, but rather by subsequent analysis of its amplitude components.

Direct-action units that work in real time are essential to diagnose the state of the operator both during the preparatory period and in the process of labor activity.

This statement points up the need to develop and use the methods of parallel and parallel-sequential processes and analyze methods of processing information in biological neuronal structures to solve the problem of physiological diagnosis of the state of the operator [19]. The use of bionic principles for preliminary processing, coding, condensing information, and above all parallel inputs and analysis of physiological parameters in real time in specialized diagnostic units will make possible a significant reduction of diagnosis time and increase its efficiency.

The thing most necessary to diagnose the state of a person using automatic devices is to have an adequately complete set of electrogram signs that reflect the functional state of the primary physiological systems of the operator. As noted above, the electrograms and distinctive signs are selected on the basis of existing medical practice and experiments that aim at identifying the information value of the particular electrograms.

The problem of image recognition in its most general form consists of identifying a certain subset characterized by some particular qualities out of a set of images presented. If the problem of automatic recognition is posed, it is necessary to indicate some procedure which an automatic system can execute, that is, its algorithm of functioning must be assigned.

To formulate such a procedure it is necessary to write, at least in general form, a mathematical model of the images to be classified.

When solving the problem of automatic classification of the state of the operator by physiological parameters, each state of the operator is usually matched against a set of electrograms as functions of one or several variables and then the recognition problem is solved in functional spaces.

The model flowchart of the recognition process in specialized devices is given in Figure 59 below. The input signal recorded from the opertor by means of a

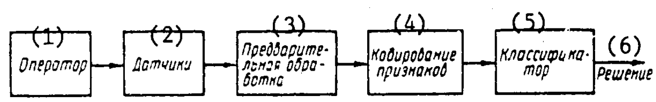

Figure 59. Flowchart of a Technical System To Monitor the State of the Operator by Physiological Parameters.

Key: (1) Operator; (2) Sensors; (3) Preliminary Processing; (4) Encoding Signs; (5) Classifier; (6) Solution.

sensor goes to the preliminary processing unit where it is amplified, filtered, and normalized. The encoder is used for a quantitative evaluation of the basic parameters of incoming electrograms. Following the encoder is a classifier, which is an adaptive decision system or a signal divider whose structure is based on a priori knowledge of the signs. The output signal of the classifier is an encoded representation of the classification images.

The choice of the method for encoding signs, in particular electrograms, plays a large part in the tasks of recognizing and classifying the state of the operator. Signs are usually selected and the method of coding chosen on the basis of a person's experience and intuition. In the case of a complex relationship between state and the signs being recorded (which is true, for example, for the EKG and EEG), however, a person's experience and intuition are inadequate.

With currently known methods of encoding continuous curves (electrograms), the number of signs can be quite considerable, up to several hundred and even thousands for just one curve [13]. It becomes difficult to construct an algorithm on their basis. This necessitates working out or choosing a method of encoding which permits maximum reduction in the volume of initial data.

There are several methods of reducing the description and encoding of electrograms today. The essential feature of these techniques is to work out a formal mathematical statement of the transition from functional space to finite dimensional space. As a result of this juxtaposition the set of functions that interests us moves to a certain domain of multidimensional space and each function newly presented for recognition is a point in this space. Then the recognition problem comes down to determining whether the point presented belongs in the given area or not.

One of the important steps in development of ways to shorten the description and encoding of electrograms has been the techniques of dispersion in factor analysis [20, 21]. In this case base functions are found which are in some sense adapted to encoding the curves under consideration. They are optimal in the sense of average static mean quadratic error, while during preliminary norming of the curve being encoded they are optimal in the sense of minimum entropy of expansion coefficients.

But practical realization of these methods encounters significant difficulties in view of the need to compute the latent vectors of very high-order matrixes. The order of the covariation matrix for electrograms fluctuates in the range 10^2-10^4. It is the difficulty of practical realization of these methods that limits their broad application for analysis of electrograms not only in specialized devices, but also using digital computers.

One of the most widespread methods that permits a significant reduction in the initial description of continuous curves with a high quality of approximate representation of the continuous process $f(t)(t_1 < t < t_2)$ is the method of expansion of the represented function $f(t)$ according to some orthogonal system of functions $\phi_i(t)(i = 1, 2, \ldots)$:

$$f(t) = \sum_{i=1}^{\infty} c_i \varphi_i(t)\,dt, \tag{6.1}$$

where

$$c_i = \int_a^b f(t)\,\varphi_i(t)\,dt. \tag{6.2}$$

Coefficients c_i are called Fourier coefficients in the expansion of function $f(t)$ by orthogonal system $\{\phi_i(t)\}$. Comparing each function $f(t)$ with a certain finite set of its Fourier coefficients, we receive the notation described above from the space of the function into finite dimensional euclidian space with a definite level of precision. This method is described in greater detail in works [13, 16], for example.

But when the orthogonal system of the function is arbitrarily selected, the structure of the domain of finite dimensional space reflecting the class of images that interests can be very complex. For this reason the task of classification, that is, determining whether the point represented belongs to this area or not, can be very difficult to realize in technical classification equipment.

Therefore, the orthogonal system of functions for all possible variations should be chosen to simplify the task of the classifier as much as possible.

3. Some Questions of Preliminary Processing of Electrograms

As has already been noted, in most cases it is not feasible in practice to make direct us: of electrogram signals taken from the sensors for encoding and classification. The levels of the signals are usually quite low and, in addition, the signal is significantly "colored" by interference caused by induction in the connecting wires in human beings, the movements of the operator, and the large spread between internal and transitional resistance of the operator at the recording points of the electrograms.

Let us briefly review some algorithms and devices for preliminary processing of electrograms that make it possible to identify the curve segments necessary for analysis, to normalize them by amplitude, and to remove noise from the recording.

Figure 60 below shows a flowchart of the preliminary signal processing unit.

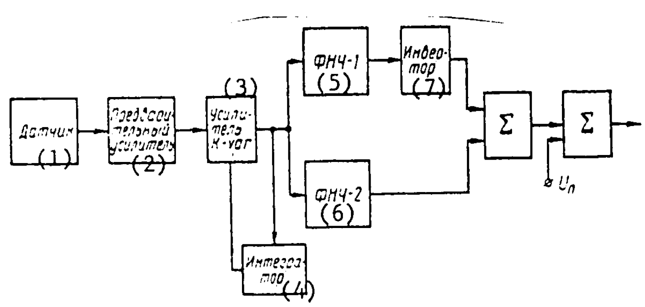

Figure 60. Flowchart of the Preliminary Electrogram Processing Unit.

Key: (1) Sensor;
(2) Preamp;
(3) K-var Amplifier;
(4) Integrator;
(5) Low-Pass Filter No 1;
(6) Low-Pass Filter No 2;
(7) Invertor.

The signal from the sensor usually goes to an amplifier with inertial automatic regulation of amplification. This type of amplifier has a number of significant advantages over other types (logarithmic amplifiers, amplifiers with high-speed automatic regulation of amplification, and the like) for amplification of electrograms. Inertial automatic regulation of amplification maintains the constancy of amplitude of the output signal with a high degree of precision, and as the input signal increases latent noise and various fluctuations which are less than the signals are suppressed in an amplifier with inertial automatic regulation. In addition, this type of amplifier is simpler in practical realization. Use of it leads to an insignificant loss of information on the individual characteristics of the operators and preserves the shape of the curve, while the constancy of signal amplitude significantly simplifies analysis of its shape.

For purposes of preliminary amplification and level stabilization, the circuit can use DC integrated microcircuit amplifiers (types K544UD1A, K284UD1A, and others) with input series on field transistors. These amplifiers have high input impedance (tens and hundreds of megaohms), a low level of latent noise (a few microvolts), a broad pass band, a large amplification factor, and low drift for the constant component.

Figure 61 below shows one variation of the circuit for preliminary amplification and level stabilization of signals. This version was obtained by modifying the well-known scheme of work [22]. The technical specifications of this layout are

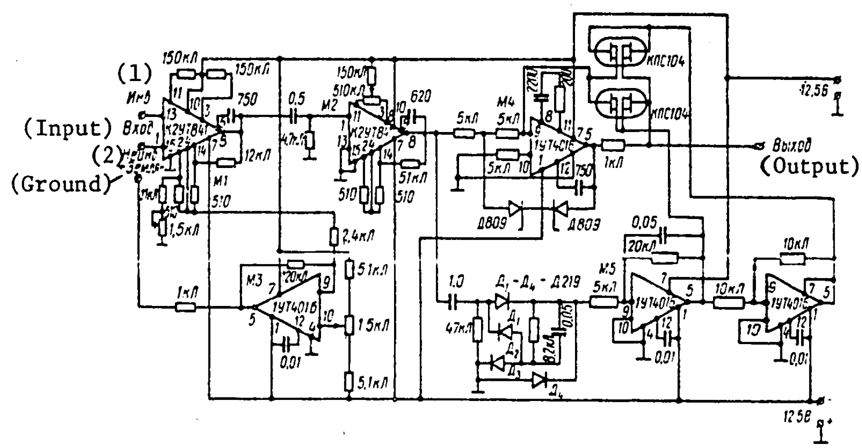

Figure 61. Schematic Diagram of Normalization of an Electrogram by Amplitude

Key: (1) Inverting;
(2) Noninverting.

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as follows:

a. input impedance in the frequency band 0.1-1,000 Hz in the range 2-5 megaohms;

b. coefficient of suppression of cophasal noise of at least 110 decibels;

c. voltage of no more than six microvolts for intrinsic noise at the input;

d. pass band within the range 0.1-10,000 Hz at the 0.9 level.

The amplification factor K_y of the first microcircuit M_1 is chosen as a small value (20-50) to preclude the influence of the constant voltage of polarization on undistorted amplification of the usable signal by expanding the dynamic range of the input series. The second series of amplifier M_2 provides amplification up to 1,000. At point (4) where the sources of the field transistors of integrated circuit M_1 are connected, inverting amplifier M_3 with an amplification factor of 40-50 is connected in. It forms negative feedback between the amplifier and the object of measurement according to the cophasal signal. The use at the output of circuit M_1 for preliminary amplification of series with a controlled amplification factor (type K284PU1) and integrating operations amplifier M_5 makes it possible to stabilize the amplitude of the signal being investigated.

The problem of removing high-frequency noise from signals being recorded and suppressing fluctuations in the constant component of the signal is very important for the preliminary signal processing unit.

One of the well-known methods of singling out signals against a background of additive noise is to pass a mixture of the signal and the noise through a filter in which the noise is suppressed, while the signal is virtually unchanged. The design of such filters is the objective of optimal filtration [23].

The filters used to single out the signal can have constant parameters or be adaptive. Calculations for filters with constant parameters is based on a priori knowledge of the characteristics of the signal and noise [23].

Because the frequency spectrum of electrograms is located in the range of sound and infrasound frequencies, active filters are most suitable for filtering signals in specialized units. These filters permit an octave greater attenuation in the suppression band and insignificant attenuation in the transmission band (high quality); at the same time, the device is small in weight and dimensions.

Figure 62 shows variations of widely used active low-frequency filters with constant parameters using discrete elements and integrated DC amplifiers [22, 24]. They have been slightly modified by the author. These filters are quite simple, reliable, and convenient for filtering high-frequency noise and induction and completely satisfy practical requirements for the quality of filtration of most signals. Because some methods of encoding the shape of the signal are figured for work with unipolar signals (positive or negative), the signal goes from the output series of the filters to the encoder with a constant component on the necessary level.

Drift in the magnitude of the constant and infralow-frequency components of the initial signal may lead to significant random change in the magnitude of the

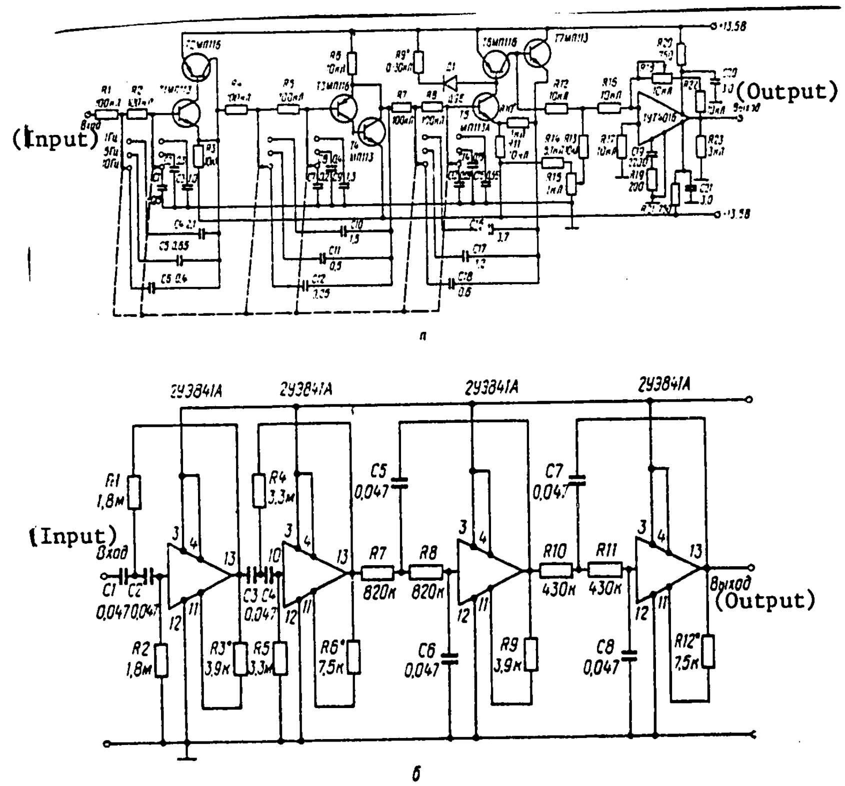

Figure 62. Diagrams of Low-Pass Filters: (a) Using Discrete Elements; (b) Using Integrated DC Amplifiers.

signs when describing the shape of the curve. Increase in the dispersion of "images" in the space of the signs leads to mutual overlapping, which reduces the quality of recognition. Change in the constant component (drift) can be significantly reduced by compensation methods. A signal which comes from an additional infralow-frequency filter can be used for these purposes (see Figure 60 above).

Analysis of the frequency range of the basic electrophysiological signals that carry information on the state of the human operator in the form of a curve (EKG, sphygmogram, electrooculogram, EEG, and others) shows that the band of their basic frequencies is higher than 0.1 Hz. This gives grounds for a frequency breakdown of the drift signals and usable signal, norming the level of the compensating drift signal, and then subtracting it in the primary channel. As a result drift noise in the primary channel is reduced or suppressed completely. The infralow-frequency filter is easily constructed following the diagram shown in Figure 62a (above). Methods of compensating for noise (high and low frequency) under stationary conditions using more complex devices and adaptive procedures are quite thoroughly covered in works [20, 21].

Adaptive filtration procedures have great potential for cleaning up usable signals. But in most cases in practice, their realization requires either digital computers or a complex specialized digital or analog computing machine, memory units, and the like. This is not always efficient when building simple specialized units to diagnose state. Therefore, we will not consider them.

After amplification, normalization, and filtration of the signals it is necessary to look for the segments of the electrograms that are needed for further encoding and recognition. This is ordinarily accomplished by threshold processing of the normalized signal. Because the basic electrophysiological curves are linked in time with cycles of cardiac activity, when processing several curves together they are usually synchronized with the EKG. One period which reflects the electrical processes occurring in the corresponding physiological system with each heart contraction is singled out from the electrograms. The EKG period is usually counted from R to R of the EKG wave because these waves have greater amplitude, shorter length, and the greatest stability. This makes it most simple and reliable to find them on a real curve.

When working with just one curve the period of analysis is between the corresponding maximums identified for this curve. The work of the entire analysis unit is then synchronized by the pulses received for the beginning and end of the period of analysis.

The segments of the curves that are selected have a significant spread by length depending on the individual characteristics of each operator. Therefore, the problem arises of normalizing the segments of the curves by length. This is simple to do in analysis systems based on digital computers. To do so norming coefficient $K = T_\phi/T$ is introduced, where T is the length of the real curve segment and T_ϕ is the standard fixed interval. Then the amplitudes of points on the curve are recalculated according to a linear interpolation expression [13].

When developing specialized devices to diagnose state, normalization of the length of the curve interval being analyzed is usually accomplished by artificial means, in each particular case beginning from the work algorithm of the unit. Therefore, the concrete variations of normalization techniques are considered in the section devoted to particular data processing algorithms in specialized diagnosis units.

4. Sequential-Parallel Analysis of the Shape of a Curve Based on Expansion According to Base Functions

Many works have been devoted to the questions of describing methods of encoding electrograms by means of systems of base functions for purposes of functional diagnosis [10, 13, 25]. But generally these questions have been considered with application to approaches oriented to processing data with digital computers. We will review some of what we think are the most interesting methods of encoding and classifying the shape of the curve in specialized diagnostic units.

From a mathematical point of view, any full orthonormal system of functions may be taken as the base functions $\phi_1(t)$, $\phi_2(t)$ ... for encoding a continuous signal, because an approximate representation of continuous function f(t) with a preassigned degree of precision is possible with any of them. But in the case of an arbitrary selection of a system of functions during technical realization of a device there often arises, in the first place, the problem of generating the set of components $\{\phi_i(t)\}$ of the system of functions selected and, in the second place, the structure of the domain of finite dimensional space in which the signal analyzed is represented in this case may be highly complex. For this reason, the structure of the classifier may also prove difficult to realize in simple specialized devices. In other words, when the system of functions is being selected attention must be paid to the possibility of realizing it.

Let us look at several systems of functions which are easily realizable in specialized technical devices for analysis, simplify the classifier, and avoid the necessity of self-instruction for the decision unit.

Suppose (a, b) is a finite interval on a real (material) axis on which two functions $f_1(t)$ and $f_2(t)$, which assume real values, are given (see Figure 63 below).

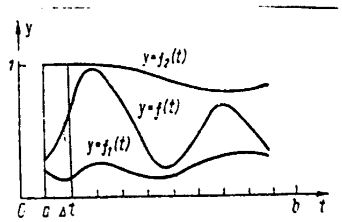

Figure 63. Encoding Electrograms by the Pulse System of Base Functions.

For the sake of simplicity we will consider functions $f_1(t)$ and $f_2(t)$ continuous in the closed interval (although, as will be seen later, this condition can be weakened). Furthermore we assume that $f_1(t) < f_2(t)$. The recognition problem will consist of automatically identifying from the set of graphs of functions given in the interval (a, b) those which are between the graphs of functions $f_1(t)$ and $f_2(t)$. It is natural to call functions $f_1(t)$ and $f_2(t)$ the lower and upper envelopes of the family of functions that interests us.

Let us divide interval (a, b) into n equal, nonoverlapping parts of length Δt (the choice of the number n is discussed below). We will construct the following system of functions using this breakdown. We assume function $\phi_i(t) (i = 1, 2, \ldots, n)$ is equal to 1 in subinterval i of the described division and to 0 at all other points:

$$\varphi_i(t) = \begin{cases} 1 & \text{for} \quad t \in \left[a + (i-1)\frac{b-a}{n}, \quad a + \frac{i}{n}(b-a)\right], \\ 0 & \text{for} \quad t \notin \left[a + (i-1)\frac{b-a}{n}, \quad a + \frac{i}{n}(b-a)\right] \\ & \qquad (i = 1, 2, \ldots, n). \end{cases}$$

From the relationships

$$\int_a^b \varphi_i(t)\varphi_j(t)\,dt = \delta_{ij}\frac{b-a}{n},$$

where

$$\delta_{ij}\begin{cases}1 & \text{for } i=j,\\ 0 & \text{for } i\neq j,\end{cases}$$

it follows that the system of functions $\{\phi_i(t)\}_{i=1}^{n}$ is orthogonal in (a, b) (although it obviously is not complete).

Corresponding to each function f(t) assigned and continuous in interval (a, b) we set n numbers in the following manner:

$$c_i(f) = \int_a^b f(t)\varphi_i(t)\,dt = \int_{a+\frac{i-1}{n}(b-a)}^{a+\frac{i}{n}(b-a)} f(t)\,dt \quad (i = 1, 2, \ldots, n).$$

Based on coefficients $\{c_i(t)\}_{i=1}^{n}$ it is possible to construct the function

$$\tilde{f}_n(t) = \sum_{i=1}^{n} c_i(f)\varphi_i(t),$$

which differs from f(t) by the quantity $\Delta_n = \max|f(t) - \tilde{f}_n(t)|$, which has the meaning of the error of the method. It is obvious that this error can be made smaller than any preassigned number by increasing the number n. This consideration is the basis for choosing the number n.

The approach described, from functional space to finite dimensional euclidian space has several special features which are what justifies its application. More precisely, from the basic characteristics of the integral (for example see work [26], it follows that if for the two functions f(t) and g(t) the following inequality is correct

$$f(t) \leqslant g(t),$$

then the following inequality is also correct.

$$c_i(f) \leqslant c_i(g) \quad (i = 1, 2, \ldots, n).$$

Therefore, if the graph of the function f(t) is between the graphs of functions f (t) and f (t) (see Figure 63 above), that is

$$f_1(t) \leqslant f(t) \leqslant f_2(t),$$

then, it follows that

$$c_i(f_1) \leqslant c_i(f) \leqslant c_i(f_2). \tag{6.3}$$

This means that a point in finite dimensional space that corresponds to function f(t) is located within or on the edges of the parallelepiped whose edges are parallel to the coordinate axes, while the points with the coordinates $\{c_i(f_1)\}_{i=1}^{n}$

(the least far from the beginning of the coordinates) and $\{c_i(f_2)\}_{i=1}^{n}$ (the furthest from the beginning of the coordinates) are located at two opposite apexes.

On the other hand, if the point in finite dimensional space corresponding in the ways described above to functions f(t) is located within or on the edges of the parallepiped described, the graph of function f(t) is located between the graphs of functions $f_1(t)$ and $f_2(t)$ (allowable error depends on the choice of number n and may be made as small as desired by increasing n).

It follows from the above that the class of images which interests us is depicted in the manner described in the parallepiped in finite dimensional space, whose edges are parallel to the coordinate axes. This makes the problem of classification much easier. It involves testing inequality (6.3) for all coefficients and may be done by an automatic classification system constructed from comparison circuits using neuron-like elements [19].

The equation for the surface of the hypercube for each coefficient has the following form

$$\sum_{j=1}^{n} |x_j - m_{ji}| - R_i = 0, \tag{6.4}$$

where m_{ji} is the mathematical expectation of sign j in standard i; and, R_i is the value of half of the diagonal of the hypercube. Obviously, the realization of x is an internal point of hypercube i if

$$\sum_{j=1}^{n} |x_j - m_{ji}| - R_i < 0. \tag{6.5}$$

The separating planes (6.4) in the neuronal classifier are formed in the manner described in work [27]. The reference voltages of the average values of the signs and length of the diagonal of the hypercube are stored in potentiometers which are set during the instruction process.

Let us consider one more system of base functions which permits simple technical realization in specialized devices. This system of functions is a modification of the Walsh functions [35]. This system of functions is continuous, so it is preferable for analyzing continuous functions because it provides more rapid convergence of expression (6.1).

Let us consider the system of piecewise-linear base functions which result from integrating the Walsh functions [36].

The Walsh functions were initially defined recursively [25]. Then work [36] showed that each Walsh function may be defined independently of the others. The first eight Walsh functions Wal (i, t) are shown in Figure 64a (below). This figure shows how the group index k is assigned. The first Walsh function Wal (0 t) is equal to +1 at (0, T/2) and to -1 at (T/2, T). Wal (2, T) and Wal (3, T) make up the next group for k = 2. The other Walsh functions make up a group of 2^{k-1} elements, k = 3, 4, ... and may be formed recursively from the elements of the preceding group.

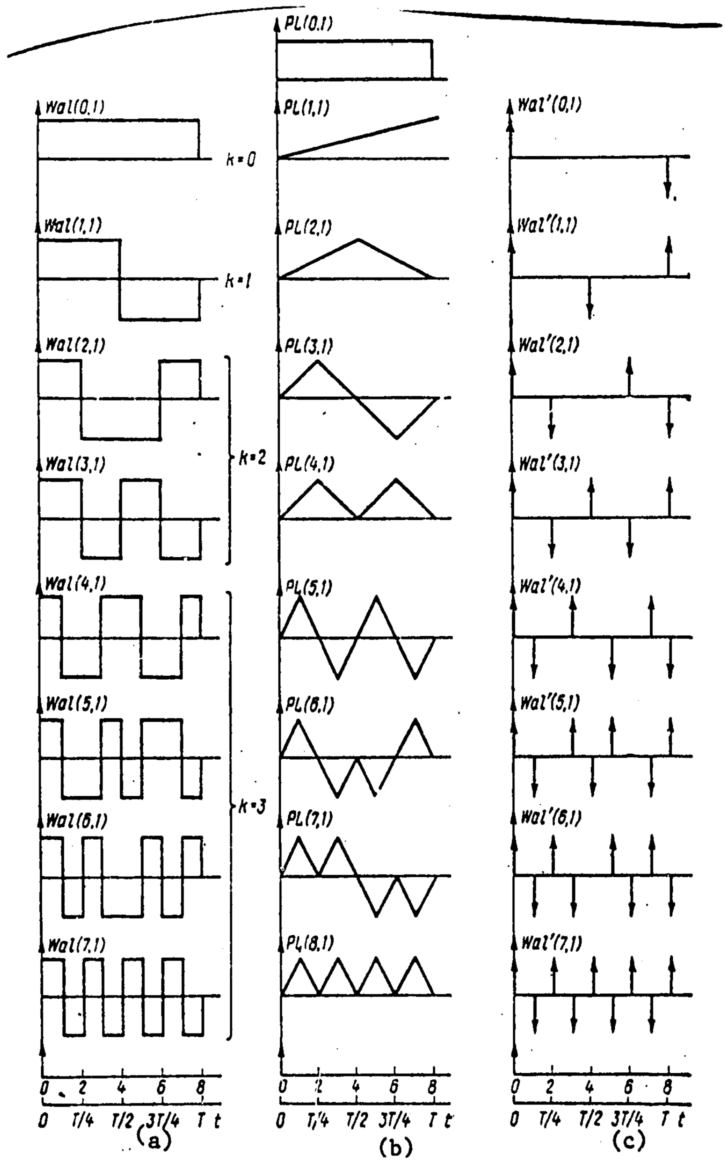

Figure 64. Systems of Base Functions: (a) Walsh, and (b, c) Piecewise Linear.

Let us define the system of base piecewise-linear functions $\{PL(i, t)\}$ as

$$PL(i+1, t) = \frac{2^k}{T}\int_0^t \mathrm{Wal}(i, \tau)\, d\tau, \quad 0 \leqslant t \leqslant T, \tag{6.6}$$

for $i = 0, 1, 2, \ldots, h$. The multiplier $2^k/T$ in (6.6) is used for normalization, while k is the group index of the original Walsh function. It is easy to show that the piecewise-linear functions are linearly independent at $[0, T]$, as are the Walsh functions. The first nine piecewise-linear functions are shown in Figure 64b (above).

The system of functions $\{PL(i, t)\}$ forms the basis of the functional space because they are linearly independent at $[0, T]$. The orthogonal base functions permit direct determination of $\{c_i\}$, as shown in (6.2).

The system of piecewise-linear functions $\{PL(i, t)\}$ is not orthonormal or even orthogonal. But this should not cause difficulties because it is easy to show that the coefficients of expansion are uniquely determined. The set of expansion coefficients c_i in (6.1) is determined as follows:

$$c_0 = f(0),$$
$$c_i = -\frac{1}{2^k}\int_0^T f(t)\,\mathrm{Wal}'(i-1, t)\,dt, \qquad i = 1, 2, \ldots, \tag{6.7}$$

where $\mathrm{Wal}'(i, t)$ is a derivative of Walsh function i or the ϕ-function, and k is the group index of $\mathrm{Wal}(i-1, t)$.

To demonstrate that there is a unique way to obtain the coefficients of expansion (6.7), we will multiply (6.1) by $\mathrm{Wal}'(m, t)$ and integrate at interval $(0, T)$:

$$\int_0^T f(t)\,\mathrm{Wal}'(m, t)\,dt = \sum_{i=0}^{\infty} c_i \int_0^T [\mathrm{Wal}'(m, t)\,PL(i, t)]\,dt =$$
$$= c_0 \int_0^T \mathrm{Wal}'(m, t) +$$
$$+ \sum_{i=1}^{\infty} c_i \int_0^T \left[\mathrm{Wal}'(m, t)\left(\frac{2^k}{T}\right)\int_0^T \mathrm{Wal}(i-1, \tau)\,d\tau\right] dt.$$

Integrating by parts considering that Walsh functions are equal to zero where $t = 0$ and $t = T$, we obtain

$$\left(\int_0^T \mathrm{Wal}'(m, t)\,dt = 0\right):$$

$$\int_0^T f(t)\,\mathrm{Wal}'(m, t)\,dt =$$
$$= -\sum_{i=1}^{\infty}\left(\frac{2^k}{T}\right) c_i \int_0^T \mathrm{Wal}(m, t)\,\mathrm{Wal}(i-1, t)\,dt,$$

from which we find, from the orthogonality of Walsh functions,

$$c_i = -\frac{1}{2^k}\int_0^T f(t)\,\mathrm{Wal}'(i-1, t)\,dt$$

for i = 1, 2, ... Because PL (i, 0) = 0 for $i \geq 1$, $c_0 = f(0)$.

Let us note that Wal' (i, t) is a sequence of delta functions with a variable sign and weight equal to two (with the exception of the final points where the weight is equal to one). Thus, equality (6.6) shows that the expansion coefficients are linear combinations of values f(t).

For example, where k = 3 the first nine expansion coefficients have the following form:

$$\begin{aligned}
c_0 &= f(0);\\
c_1 &= -[f(0) - f(T)];\\
c_2 &= -{}^1/_2\,[f(0) - 2f(T/2) + f(T)];\\
c_3 &= -{}^1/_4\,[f(0) - 2f(T/4) + 2f(3T/4) - f(T)];\\
c_4 &= -{}^1/_4\,[f(0) - 2f(T/4) + 2f(T/2) - 2f(3T/4) + f(T)];\\
c_5 &= -{}^1/_8\,[f(0) - 2f(T/8) + 2f(3T/8) - 2f(5T/8) +\\
&\quad + 2f(7T/8) - f(T)];\qquad\qquad (6.8)\\
c_6 &= -{}^1/_8\,[f(0) - 2f(T/8) - 2f(3T/8) - 2f(T/2) +\\
&\quad + 2f(5T/8) - 2f(7T/8) + f(T)];\\
c_7 &= -{}^1/_8\,[f(0) - 2f(T/8) + 2f(T/4) - 2f(3T/8) +\\
&\quad + 2f(5T/8) - 2f(3T/4) + 2f(7T/8) - f(T)];\\
c_8 &= -{}^1/_8\,[f(0) - 2f(T/8) + 2f(T/4) - 2f(3T/8) + 2f(T/2) -\\
&\quad - 2f(5T/8) + 2f(3T/4) - 2f(7T/8) + f(T)].
\end{aligned}$$

Any continuous signal can be represented by means of this system of piecewise-linear functions.

Because many engineering problems of approximation include piecewise-linearization [15, 28], this form of representation has certain advantages over other base systems. In particular, the use of this base makes it possible to choose the necessary type of piecewise-linear approximation a priori and immediately determine the number of base functions necessary to achieve the assigned precision of point approximation.

The next advantage of the base {PL(i, t)} consists in the fact that the functions are formed by means of Walsh functions. This makes it possible to use familiar realization schemes. Because the operation of shaping the system {PL(i, t)} is a weighted integration of Walsh functions, it becomes unnecessary to generate piecewise-linear functions when restoring the signal.

There is no question that a great advantage of the piecewise-linear basis is that the coefficients of expansion are determined in a trivial manner, as a linear combination of values of the function being expanded, and in this case it is not necessary to multiply out the functions and integrate the results. Moreover, the corresponding linear combinations are found through derivative Walsh functions which may be formed recursively because the linear combinations are determined without complex computations.

The area of assignment of each of the states (set of corresponding curves) in the system of functions presented may also be depicted in the form of a hypercube. The equation for the surface of this hypercube is described by expression (6.4), while the classification is done according to expression (6.3). The sign of the curve being analyzed must be made constant for this.

Figures 65 and 66 below show flowcharts of devices for encoding electrograms by these systems of functions.

Let us consider the flowchart in Figure 65. The sample interval Δt (time of computation of coefficient c_i) in the circuit of the unit is assigned by means of controlled cycle frequency generator 3, decoder-register 9, and the set of analog key elements 10. At the output of the seuqentially switchable key elements are installed integrators 11, which execute the transformation

$$c_i(f) = \int_{a+\frac{(i-1)}{n}(b-a)}^{a+\frac{i}{n}(b-a)} f(t)\, dt.$$

The values of all coefficients at the end of interval T are analyzed by parallel classifier 13 on neuronal (or threshold) elements. The classifier tests condition (6.5) for each coefficient.

As the results of research have shown, 16-20 coefficients $c_i(f)$ are sufficient to analyze most electrograms with a relatively high level of detail. The parallel principle of construction of the classifier greatly simplifies the problem of "memory" and generating the system of base functions. Because the system of base functions under consideration is not invariant to the length of the interval of analysis T, the scheme envisions constructing sampling interval Δt of the system of base functions when the interval of analysis T changes by means of convertors: length of period T → voltage 4 → frequency of generator 3 and transfer coefficient of amplifier 2. It is very difficult to control the length of the initial signal without using complex and expensive memory units with long-term memory and variable reading speed. It is much simpler to change the frequency of generation of the system of base functions and, in accord with this, normalize the amplitude of the signal. The other functional relations are fairly clear from the figure.

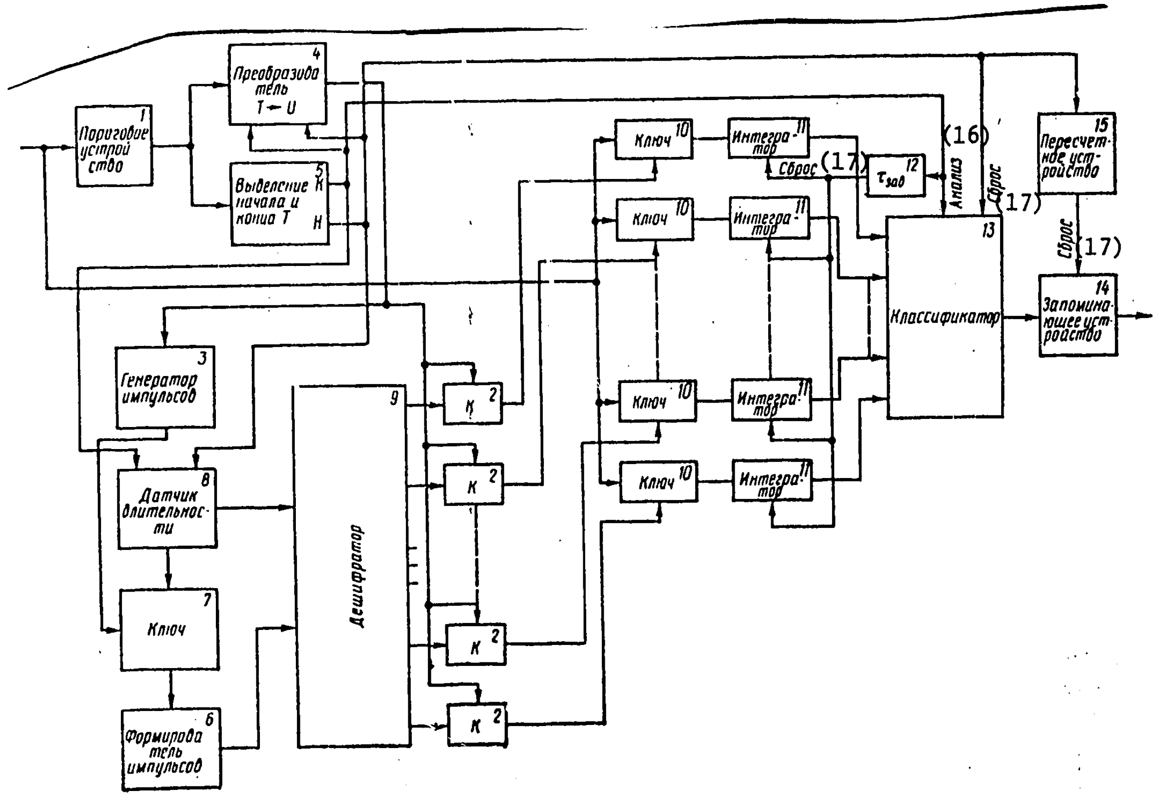

Figure 65. Flowchart of an Analyzer of the Operator's State Using the System of Pulsed Base Functions.

Key:
(1) Threshold Unit;
(2) Coefficient;
(3) Pulse Generator:
(4) T → U Convertor;
(5) Identification of Beginning (H) and End (K) of T;
(6) Pulse Shaper;
(7) Key;
(8) Length Sensor;
(9) Decoder;
(10) Key;
(11) Integrator;
(12) $\tau_{зад}$;
(13) Classifier;
(14) Memory Unit;
(15) Recalculation Unit;
(16) Analysis;
(17) Clear.

Figure 66 below shows the flowchart of an analyzer of the shape of the curve based on the piecewise-linear system of base functions. The moments of interrogating the analyzed signal are also determined by means of a generator of Walsh functions 6, a device to identify the points where Walsh functions pass through zero 8, a circuit to identify the sign of the derivative 9, and decoder 7. The value of coefficient c_i and its sign are computed by an appropriate switch of the input signal using key elements 11 and decoder 7 at moment t_i to the input of the

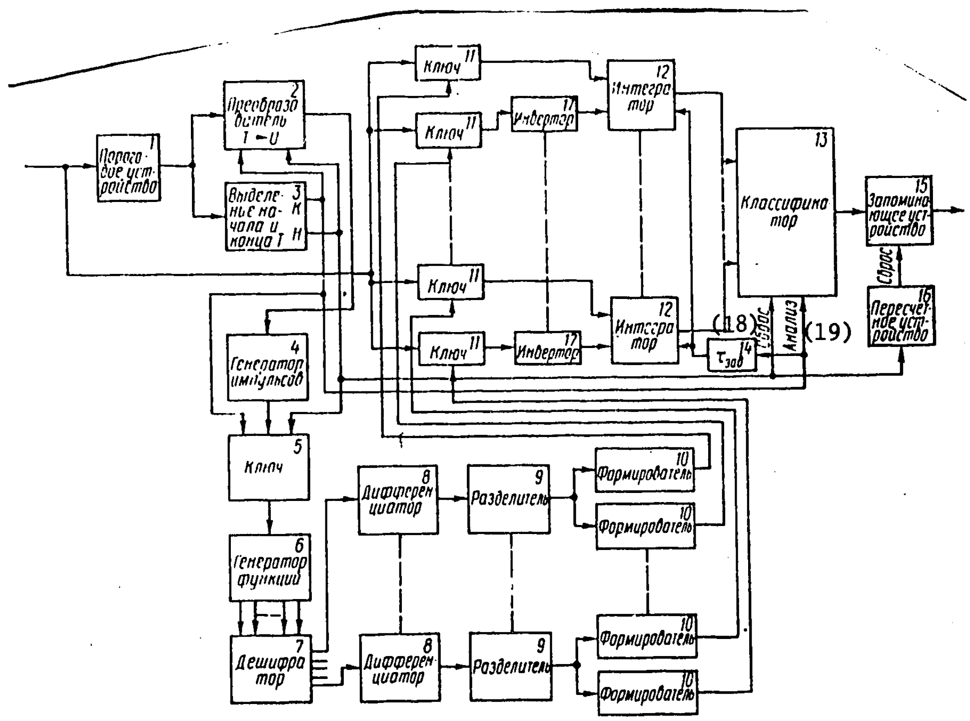

Figure 66. Flowchart of Analyzer of Operator's State Using System of Piecewise-Linear Base Functions.

Key:
(1) Threshold Unit;
(2) T → U Convertor;
(3) Identification of Beginning (H) and End (K) of T;
(4) Pulse Generator;
(5) Key;
(6) Function Generator;
(7) Decoder;
(8) Differentiator;
(9) Divider;
(10) Shaper;
(11) Key;
(12) Integrator;
(13) Classifier;
(14) $\tau_{зад}$;
(15) Memory Unit;
(16) Recalculation Unit;
(17) Invertor;
(18) Clear;
(19) Analysis.

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summing amplifier with short-term memory based on integrator 12. At the moment of completion of interval T the parallel classifier evaluates the value of the coefficient and makes a decision. The scheme also envisions adjustment of the generator of the cyclical frequency of interrogating the input signal 4 (base function generator) when there is a change in the magnitude of interval T.

It is interesting that the solution to the problem of classifying situations contains three stages: description of the classes (encoding) of situations, synthesis of the dividing surface, and making a decision on the affiliation of the given state with one of the classes of states. Let us consider in more detail some questions of synthesizing the dividing surface. At the present time the theory of elementary classifiers has been broadly developed. These classifiers divide the assigned situations or images into two classes by means of a linear discriminant function [13, 21].

Let us assume that a situation is represented by a set of signs $x_1, x_2, \ldots, x_n$. They are constituent parts of n-dimensional vector X. We will designate the m possible classes of states $\omega_1, \omega_2, \ldots, \omega_m$. The job of the situation classifier being trained is to assign each given vector of signs x_i to a definite class of situations ω_j. The ultimate goal of training is an optimal division of n-dimensional vector space into m nonintersecting areas. The boundary or decision surface can be determined by means of discriminant function $d_i(X)$, $i = 1, 2, \ldots, m$. It is selected so that if X_i belongs to situation ω_i, then $d_i(X) > d_j(X)$ for all $i \neq j$. This means that if the object being monitored is in a certain class of states, this should insure the extremum of the corresponding discriminant function, which differs from the values of the other functions. This function should assume the largest value of all the others.

The decision surface between classes of states ω_i and ω_j is described by the equation

$$d_i(X) - d_j(X) = 0. \tag{6.9}$$

It is a hyperplane of a particular system of complexity.

The natural desire to simplify the classification scheme leads to attempts to simplify the form of the boundary surfaces. This is done mainly by replacing nonlinear decision hypersurfaces with linear ones, that is, hyperplanes. In this case the decision surface is described by the equation

$$f(x) = d_i(X) - d_j(X) = \sum_{r=1}^{k} (\omega_{ir} - \omega_{jr}) x_r + (\omega_{i,k+1} - \omega_{j,k+1}) = 0.$$

suppose $\omega_r = \omega_{ir} - \omega_{jr}$, $r = 1, 2, \ldots, k+1$, ; then expression (6.9) assumes the form

$$\sum_{r=1}^{k} \omega_r x_r + \omega_{k+1} = 0.$$

Study of the properties of biological neurons and modeling them demonstrated that the existence of threshold characteristics and the presence of a linear analog segment of the input-output characteristic enable biological analyzers to broaden the logical capabilities of neuron networks and realize fundamentally neurological functions. This makes it possible to transfer from one logical function to another. Modeling analog and discrete characteristics of the neuron in technical analogs and using them to construct monitoring systems substantially broadens the capabilities of these systems [19].

While considering the algorithm of functioning of the neuron, it may be noted that the frequency of generation of pulses at its output depends on the amount by which the sum input signal exceeds the threshold signal. We know that the functioning of a neuron is described by the expression

$$\vartheta(t)=\begin{cases}k\left(\sum_{i=1}^{n}a_ix_i-\Theta\right) & \text{for} \quad \sum_{i=1}^{n}a_ix_i>\Theta,\\ 0 & \text{for} \quad \sum_{i=1}^{n}a_ix_i\leqslant\Theta,\end{cases} \tag{6.10}$$

where $\vartheta(t)$ is the frequency of pulse generation at the output of the neuron; a_i is the magnitude of synaptic coefficient i; x_i is the numerical value of the input action; Θ is the neuron threshold; k is the steepness of the input-output characteristic of the neuron; and, n is the number of inputs of the neuron.

A comparison of expression (6.9) and (6.10) makes it obvious that the neuron realizes a hyperplane in the space of the input signals and is a decision element. When the vector-image $X\{x_1, x_2, \ldots, x_n\}$ is presented to the neuron, it may be either excited or not excited. If the neuron is not excited, this means that the linear function $y = X^t A - \Theta$ is less than zero at the point represented by set $\{x\}$, and the end of the vector is outside the hyperplane (on one of the sides of the space). In this case $A = a_1, a_2, \ldots, a_n$ is the vector of weight coefficients. If the neuron is excited, the linear function assumes a value greater than zero and the end of the vector is located in another area relative to the hyperplane. Therefore, the neuron assigns every set of input signals to one of the semispaces, and this division is accomplished by means of the linear function $y = X^t A\ \Theta$.

Thus, the neuronal structure can realize a large number of hyperplanes and evaluate the location of the point that depicts input information. By changing the weight of particular "synapses" and the value of threshold Θ, we obtain dividing hyperplanes $y_1, y_2, \ldots, y_n$, whose slope can be changed in the process of training or adjustment.

It is clear from the above that devices that model the primary characteristics of the neuron can be used for the purpose of shaping the dividing situation of a surface, and will simplify the classifier in this case.

A large number of various devices have been developed today that model the primary functional capabilities of the biological prototype (29, 30). A number of algorithms have been written for adjusting the weight coefficients and threshold according to the set of situations presented in order to optimize the quality of situation recognition. Most of the training algorithms proposed for linear adaptive situation recognition devices are systems that search for the vector of weight coefficients and neuron thresholds and minimize a preassigned error function. The gradient method is most widely used [31].

The neuronal classification structures obtained by changing the training procedure are much simpler than classifications on digital computers. Some variations of them are considered below.

5. Encoding Time Functions by Artificial Neuron Nets According to Their Informative Signs.

Let us consider one more method of encoding complex time functions, based on using the principles of processing data in the sensory systems of biological systems.

Research done by Eccles, Matthews, E. I. Katets, P. G. Kostyuk, and others on stimulation of nerve-muscular structures has identified the basic principles of neuron processing of time signals [28, 32]. They showed that the reaction of nerve tissue is described by the expression

$$W = f\left[U(t), \int_0^\tau U(t)\,dt\right],$$

where U(t) is the amplitude of the signal; τ is its length; and, $\int_0^\tau U(t)\,dt$

is the energy component of the stimulus signal. Thanks to the action of the adaptation mechanism, the excitability of nerve tissue depends significantly on the first and second derivatives of the stimulating signal. Therefore, its reaction is expressed by the function

$$W = f\left[U(t), \int_0^\tau U(t)\,dt, \frac{dU(t)}{dt}, \frac{d^2U(t)}{dt^2}\right],$$

whose independent variables are the primary components of the signal. Each of these components has its own weight (α, β, γ, δ) so control of excitability in general form can be represented linearly:

$$\alpha U(t) + \beta\frac{dU(t)}{dt} + \gamma\int_0^\tau U(t)\,dt + \delta\frac{d^2U(t)}{dt^2} = 1.$$

The mechanism of adaptation, which influences the process of encoding signals, is linked to the interaction of the processes of stimulation and inhibition in the membrane of the neuron and, dynamically, to the characteristics of the neuron. Analysis of processes on the membrane permits us to hypothesize that the passing stimulation signal triggers a simultaneous inhibiting process which develops exponentially and compensates for the stimulating process after interval τ.

The process of conversion of information in the synaptic cell and summator of the neuron leads to the structural diagram shown in Figure 67 below. Link 1 of the diagram is proportional to the input signal. Link 2 with the transfer function of the aperiodic link develops reactive inhibition. The transfer function of the summator is represented by aperiodic link 3. The transfer function of this segment of the neuron model is described by the expression

$$W_0(p) = \frac{[k_1T_1p + (k_1 - k_2)]\,k_3}{(T_1p + 1)(T_2p + 1)}.$$

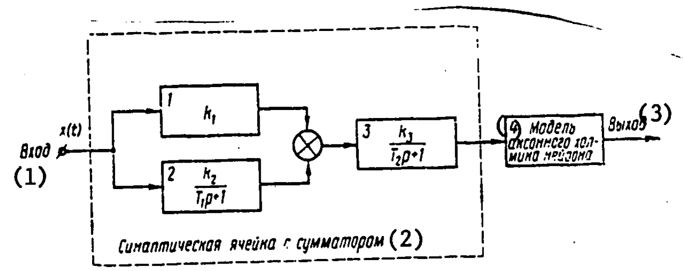


Figure 67. Flowchart of a Neuron Model.

Key: (1) Input;
(2) Synaptic Cell with Summator;
(3) Output;
(4) Model of Axon Hillock ["Kholmik"] of Neuron.

Because $T_1 \gg T_2$, delay in the summator may be ignored. The transfer function assumes the form

$$W_{01}(p) = \frac{k_1T_1p + (k_1 - k_2)}{T_1p + 1}.$$

On the condition that $k_1 = k_2$ (inhibition completely compensates for stimulation), it is converted into the transfer function of the differentiating link

$$W_{02}(p) = \frac{k_1T_1p}{T_1p + 1}.$$

Investigations of neurons of different modalities lead to the conclusion that the neuron is the differentiating element of the nervous system. Neuron-type "on," "off," and "on-off" reactions also testify to this [28-30].

The potential that develops according to the transfer function acts on the threshold generator of standard pulses 4. As a result, the output signal of the neuron is described by the expression

$$y(t) = kL^{-1}\left\{W_{\text{н}}(p) \sum_{i=1}^{n} a_i x_i(p)\right\} - \Theta,$$

where L^{-1} is an inverse Laplace transform, and k is the coefficient of amplification of the conversion characteristic of the neuron. The neuron or neuron ensemble realizes a certain transfer function only on the condition that

$$\sum_{i=1}^{n} a_i x_i(t) > \Theta.$$

Combining the positive and negative rigid and flexible feedbacks, it is possible to receive a number of essential transfer functions of neuron structures. Thus, in Figure 68 below part a shows a structure with a transfer function $W_H(p) = kTp$ (differentiating link or neuron with rapid adaptation), while part b shows a structure with a transfer function $W_H(p) = k/2T \times 1/p$ (integrating link).

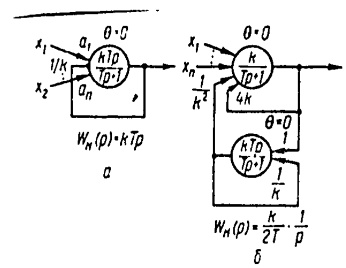


Figure 68. Functional Model of (a) Differentiating Neuron, and (b) Integrating Neuron.

These characteristics of the neuron model were used to encode the informative points of the shape of the curve of electrograms. The ability of neurons and ensembles of neurons to single out the informative components of time functions was investigated on technical models of neurons including synaptic cells and a model of a neuron with summator. The basic synaptic cell is an operational amplifier that works in the regime of an aperiodic filter with time constant τ depending on the parameters of the circuit.

When it is stimulated the threshold of the neuron increases exponentially $U_H = U'_{CT} \exp(-t/\tau)$, where U'_{CT} is the amplitude of the stimulus. Change in the stimulating postsynaptic potential is described by the expression

$$U_{\text{впсп}} = -U'_{\text{ст}} - U_n = -U'_{\text{ст}}\left(1 - e^{-\frac{t}{\tau}}\right),$$

where $U_{\text{впсп}}$ is the amplitude of the stimulating postsynaptic potential. Figure 69 below shows change in U_n and $U_{\text{впсп}}$. An "on" reaction or adaptation is obtained at the output of the neuron model depending on the value of τ selected.

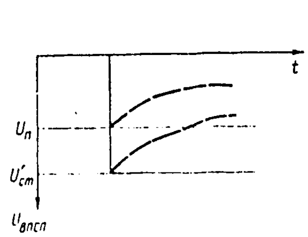


Figure 69. Change Over Time in Total Signal at Input of Neuron Model.

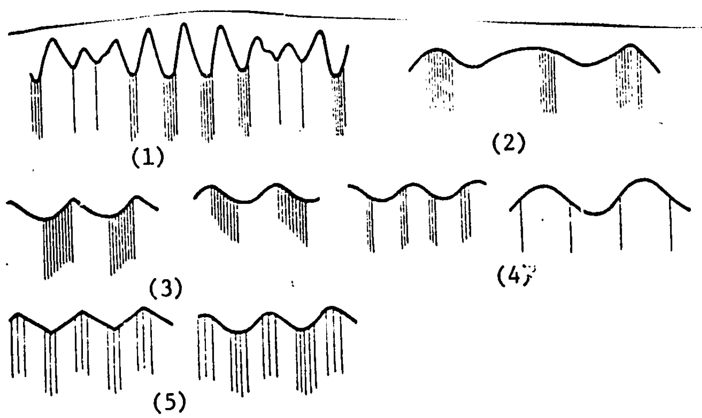


Figure 70. Example of Neuron Coding:

Key: (1) Minimums of Time Signal;
(2) Maximums of Time Signal;
(3) Positive and Negative Derivatives of Input Signal;
(4) Points of Signal Passage Through Conventional Zero;
(5) Maximums and Minimums of Time Signal.

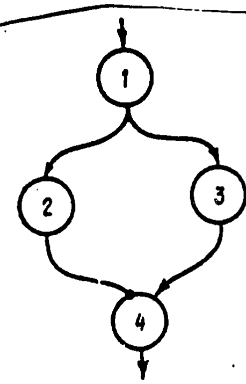
To obtain a code that is invariant to the magnitude of the amplitude of the signal being analyzed, it is enough to feed it to the input of the neuron structure shown in Figure 71 below. Work [33] considers the mechanisms of identification of the informative components of a signal in greater detail.

It can be seen from the above that differentiating neurons and ensembles of them efficiently convert continous functions and can be used as devices to feed information to a digital computer or classifying neuronal structure. The task of the latter may be reduced to comparing the time intervals between informative points of the time code with standard intervals and outputting the results of this process.

Measurement of the time interval between two packages of pulses and production of the signal when it is located within the established clearances can be done by means of a neuron ensemble (see Figure 72).

It is possible to identify a broad class of informative components of the time signal by means of individual neurons and elementary neuron ensembles by changing their thresholds and the parameters of the synaptic cells included in the stimulating and inhibiting inputs of the neuron (see Figure 70 below). This ensemble

Figure 71. Neuron "Norming" Structure.



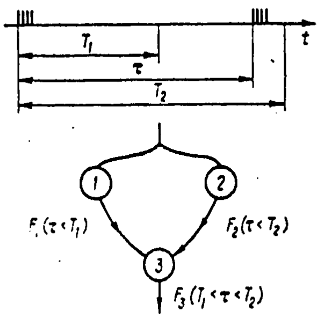
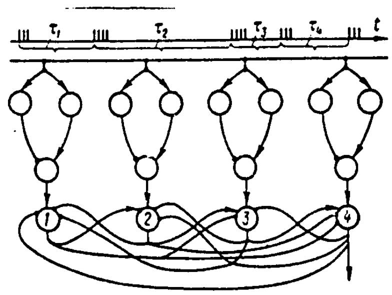


Figure 72. Neuron Structure for Identifying a Given Time Interval.

uses elements with short-term memory. Neurons 1 and 2 of the ensemble realize the logical time functions $F_1(\tau < T_1)$ and $F_2(\tau < T_2)$ respectively when $T_2 > T_1$, where τ is the ongoing time interval between packages, and T_1 and T_2 are the lower and upper permissible values of time intervals. Neuron 3, which realizes the function $F_3(T_1 < \tau < T_2)$ will be stimulated only on the condition that $T_1 < \tau < T_2$. Having a set of time function detectors of the type $F(T_{1i} < T < T_{2i})$, it is possible to construct a neuron structure that reacts only to a definite code of the informative signs of the process. Such a structure is shown in Figure 73 below. The circuits of the neuron detectors are tuned to the time intervals between packages of pulses coming sequentially in the code, and alternately stimulate neurons 1, 2, 3, and 4. A signal appears at the

Figure 73. Neuron Structure for Identifying a Given Sequence of Time Intervals.



output of the neuron structure (neuron 4) only if the intervals between packages are within the established clearances, that is, the structure realizes the function

$$\overline{F\begin{pmatrix}\tau_1 \pm \Delta\tau_1\\ \tau_2 \pm \Delta\tau_2\\ \tau_3 \pm \Delta\tau_3\\ \tau_4 \pm \Delta\tau_4\end{pmatrix}} = \overline{F_1(T_{11} < \tau_1 < T_{21}) \vee F_2(T_{12} < \tau_2 < T_{22}) \vee}$$
$$\vee F_3(T_{13} < \tau_3 < T_{23}) \vee F_4(T_{14} < T_4 < T_{24}),$$

where the symbol $\vee$ means conjunction.

In the general case, a chain of an arbitrary number of R neurons equal to the number of packages of pulses in the code, realizes for process i a logical time function of the type

$$\overline{F_i(\tau_r)} = \prod_{r \in R} \overline{F_r(\tau_{ir} < \tau_r < \tau_{jr})}.$$

Thus, the differentiating and special characteristics of neurons and ensembles of neurons may be used in monitoring the state of an operator for efficient conversion of time functions with subsequent analysis of them and decision-making.

Let us briefly look at the flowchart of the unit to analyze the shape of a curve based on its informative signs using the neuron structures considered above. Figure 74 below shows the flowchart of the unit.

The differentiating block is used to receive the derivative of the input signal. The block for analyzing the shape of the curve identifies typical segments of the shape of the curve under analysis f(t) and its derivative f'(t), specifically the segments with the positive derivative

$$\left(\frac{df(t)}{dt} \text{ and } \frac{df'(t)}{dt}\right);$$

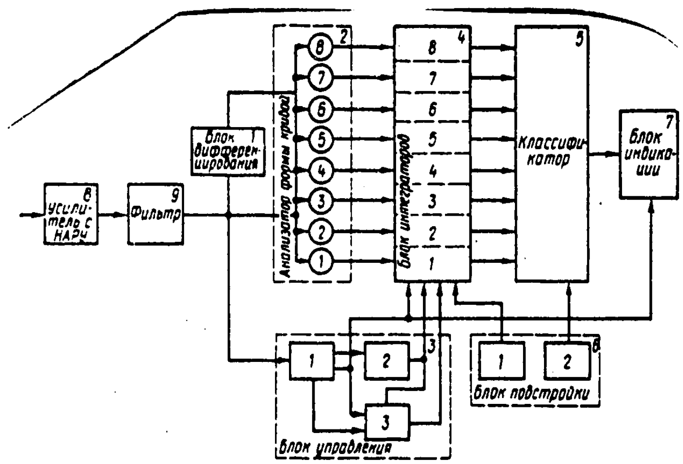


Figure 74. Flowchart of a Unit To Analyze the State of the Operator by the Shape of Electrogram Curves.

Key:
(1) Differentiation Block;
(2) Curve Shape Analyzer;
(3) Control Block;
(4) Integrator Block;
(5) Classifier;
(6) Adjustment Block;
(7) Indicator Block;
(8) Amplifier with IARU [Intertial Automatic Regulation of Amplification];
(9) Filter.

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the segments with the negative derivative

$$\left(-\frac{df(t)}{dt} \text{ and } -\frac{df'(t)}{dt}\right);$$

the maximums (max f(t) and max f'(t)); and, the minimums (min f(t) and min f't)). To identify these segments in the initial signal models of adaptive neurons 2_1–2_4 are used, while models of neurons 2_5–2_8 are used for the derivative of the input signal. In this case one model of the neuron and adaptation 1 is sufficient to identify the required segment of the shape of the curve.

The averaging block is used to average the signs of the signal identified during several periods of the analyzed curve. It has common control input for all averagers ("Initial Position," "Start," and "Stop") and an input to compensate for change in the rhythm in the analyzed curve.

The classifier is used for automatic recognition of the physiological state of the operator based on results of parallel analysis of curve signs. It may be made with operational amplifiers or models of neurons. Figure 75 below gives the structure of a classifier built on models of neurons 8-15. The classifier also has regulating inputs for individual adjustment where the period of the analyzed curve is changed by changing the thresholds of output neurons 13-15.

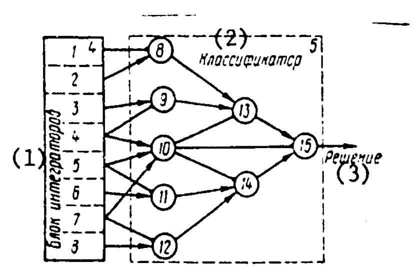

Figure 75. Flowchart of Neuron Classifier.

Key: (1) Integrator Block;
(2) Classifier;
(3) Decision.

The indicator block serves to display the results of diagnosis.

The control block consists of switch-on circuit 3_1, comparison circuit 3_2, and counter 3_3. It sets blocks 4 and 7 at zero, and selects the moments for starting and stopping averagers 4 after a certain number of periods of the analyzed curve given by counter 3_3.

Adjustment block 6 is used to take account of certain individual characteristics of the operator being tested during the diagnosis process. It contains a circuit to take account of change in the rhythm of the analyzed curve 6_1, and an individual adjustment circuit 6_2.

The work of the shape analysis unit involves the following. The signal goes from the sensor to amplifier 8, which has IARU, and filter 9, where it is normalized by amplitude and high-frequency noise and infralow-frequency drift are filtered out. It is then fed to the input of the block for analyzing the shape of the curve, directly and through differentiating block 1 with the purpose of broadening the initial set of signs. Block 2 identifies the signs of the curve indicated earlier and sends them into the integrator block.

In block 3 the signal being investigated goes to switch-on circuit 3_1. When it is triggered, the signal goes to a comparison circuit 3_2 where, after threshold processing, it produces a pulse to prepare all circuits for work. In addition, the signal launches cycle counter 3_3. After cycle counter 3_3 is filled upon completion of the assigned number of periods of analysis T, a stop signal is produced for all processing and result-recording blocks.

Averaging the signs in block 4 makes it possible to reduce the impact of random factors on reliability of processing. The averaged values of the signs, which are invariant to change in the rhythm of the analyzed curve, are fed to the input of classifier 5. It performs parallel analysis of the signs of the initial curve that are identified and operates as a difference-type neuron structure pre-trained according to the averaged values of the signs of the analyzed curve. During the process of training the classifier, the signs which increase, decrease, or remain constant for pathological states of the organism relative to the normal state are grouped and then the corresponding changes are underlined and divided by a set of hyperplanes using difference processing.

Appropriate corrections are fed to the thresholds of the output neurons from block 6_2 to eliminate individual differences of different operators.

The indicator block may produce a quantitative evaluation of the physiological system parameter being monitored or a "suitable" — "unsuitable" signal in the case of admittance monitoring.

6. Neuron Analyzer of Operator Reaction

Depending on the type of activity and jobs performed by the operator, the methods and criteria for evaluating work capability or operator suitability for the particular type of work may vary greatly. We have considered methods of continuous monitoring by physiological parameters. Sometimes it is necessary to monitor the state of operators and their professional suitability for performance of an assignment only at certain moments in time, for example when an operator is preparing for work. Naturally, all the methods presented above are suitable for this mode of monitoring and evaluating the state of the operator.

We will consider below the test method of checking operator reactions using a monitoring device built with neuron elements. In most such cases abrupt changes in the situation are possible in the work of the operator. The trajectory of change from one state of the control system to another is usually not rigidly assigned, and the operator must be guided only by the limitations imposed for the maximum and minimum values of the monitored parameters that are changing. Vivid examples of such operator activity are the work of the driver of a motor vehicle, a pilot, a dispatcher, and the like. The criterion of success for performance of the job by the operator which is usually selected in such cases is the degree of disagreement.

The problem of evaluating the operator's ability to do such work can be solved by modeling the control object using appropriate test signals.

Methods of diagnosis by parameters of labor activity have one significant drawback — the lack of information on the tension of operator work and the physical and mental expenditures of the operator in performing the task. But they allow a good evaluation of the operator's level of training, fatigue, and the like. We will begin with the stipulation that the work and evaluation of state are done on an analog of the controlled system, under working conditions, and immediately before performance of the specific task. The multifaceted "man-machine" control system permits stimulation of the input and has corresponding sensors of the output signal that take account of the operator's control action on the control system.

If the monitored "man-machine" system permits stimulation of the input, comprehensive monitoring can be accomplished by a method based on the following considerations [34].

Suppose that stimulating signal x(t) is fed to the input of a dynamic system described by a transfer function of the following type

$$W(p) = \frac{Q_m(p)}{P_n(p)} \quad (n \geqslant m),$$

where $Q_m(p)$ and $P_n(p)$ are exponential polynomials of m and n respectively, and p is a representation of the differentiation statement d/dt.

To simplify analysis of the output signal and subsequent decision-making on correction of the transfer function we will demand that the output signal y(p) meet the following conditions: output signal y(t) should be n times the continuously differentiated function; the differential relations

$$r_0 = \frac{d_0(t)}{d_1(t)} = \text{const}, \quad r_1 = \frac{d_1(t)}{d_2(t)} = \text{const}, \quad \ldots, \quad r_{n-2} = \frac{d_{n-2}(t)}{d_{n-1}(t)} = \text{const},$$

where

$$d_0(t) = \frac{y(t)}{y'(t)}, \quad d_1 = \frac{y'(t)}{y''(t)}, \quad \ldots, \quad d_{n-1}(t) = \frac{y^{(n-1)}(t)}{y^n(t)},$$

should be constant; $d_0(t), \ldots, d_{n-1}(t)$, $r_0, \ldots, r_{n-2}$ are called the first and second differential relations respectively. Specifically, the following statement must be realized

$$r_0 = \frac{y(t)\,y''(t)}{[y'(t)]^2} = \text{const}.$$

Let us note that

$$\left(\frac{y(t)}{y'(t)}\right)' = \left[y''(t)^2 - \frac{y(t)\,y''(t)}{[y'(t)]^2}\right] = 1 - r_0.$$

Integrating both parts, we receive

$$\frac{y(t)}{y'(t)} = (1 - r_0)\,t + A, \tag{6.11}$$

where A is an arbitrary constant. The case where $r_0 = 1$ does not interest us because relations $d_i(t)$ are already constant.

Having designated $1 - r_0 = \alpha$ and solved equation (6.11), we find y(t) in the form

$$y(t) = c\,(t + D)^{\beta},$$

where $\beta = 1/\alpha$. For this function the relations α_i and r_i will take the form

$$\alpha_0 = \frac{1}{\beta}(t + D), \quad r_0 = \frac{\beta - 1}{\beta},$$

$$\alpha_1 = \frac{1}{\beta - 1}(t + D), \quad r_1 = \frac{\beta - 2}{\beta - 1},$$

$$\alpha_k = \frac{1}{\beta - n}(t + D), \quad r_{n-1} = \frac{\beta - n}{\beta - n + 1}. \tag{6.12}$$

The desired function also exists for whole ϕ. In this case we have $(\beta - 2)$ nonzero secondary relation.

Let us fix the arbitrary constants $c = 1$ and $D = 0$ then the function $y(t) = t^n$. It is not difficult to check condition (6.12) for it.

The constant relations r_1 may be used for admittance evaluation of the monitored operator and to decide on the advisability of continuing to use this operator in the given situation. Knowing the required output signal and the transfer function of the monitored system, it is not hard to find the corresponding stimulating signal x(t).

Beginning from the definition of the transfer function

$$W(p) = \frac{L[y(t)]}{L[x(t)]} = \frac{Q_m[p]}{P_n[p]}$$

and performing an inverse Laplace transform, we receive

$$\frac{y(t)}{x(t)} = \frac{Q_m\left(\frac{d}{dt}\right)}{P_n\left(\frac{d}{dt}\right)}. \tag{6.13}$$

Substituting the value of y(t) found into (6.13) we have

$$P_n\left(\frac{d}{dt}\right) t^n = Q_m\left(\frac{d}{dt}\right) x(t).$$

From the last equation, knowing coefficients $a_0, a_1, \ldots, a_n$ of exponential polynomial $P_n(d/dt)$ and $b_0, b_1, \ldots, b_m$ of exponential polynomial $Q_m(d/dt)$, we find x(t) as the solution of the resulting differential equation with constant coefficients and an exponential polynomial in the righthand part. In the general case the stimulating signal is an exponential time polynomial

$$x(t) = \sum_{i=1}^{n} a_i t^i.$$

Representation of continuous input and output signals by a segment of an exponential time series is economical from the standpoint of physical realization. This has been confirmed by many studies of the mechanisms of encoding the information of the sensory systems of living organisms.

We know that neurons which have "on-off" reactions are the foundation of the structure of biological mechanisms for encoding information. Analysis of the neuron transfer function [35]confirms the hypothesis that such neurons are threshold differentiating elements. The differentiating spatial characteristics of receptive fields [33] and the possibility of expanding continuous functions into time series [28] may testify to the uniform mechanism of encoding information contained in the input signals of the sensory systems.

The differentiating and threshold characteristics of the neuron are the basis of the neuron structure that singles out the first and second differential relations and makes the decision on the functional suitability of the dynamic system being monitored.

Figure 76 below shows such a structure. It works as follows.

A standard stimulus formed with due regard for the order of the transfer function and its coefficients is fed to the output of the dynamic system. The output signal analyzed, which is taken from the sensor of the system controlled by the operator, goes to a sequential chain of differentiating first-layer neurons which possess the property of unilateral differentiation, because analysis of the reaction is done in a monotonically rising segment. The neuron thresholds P are selected on the condition $\theta = 0$.

Each of the first differentiating relations is obtained by means of a structure consisting of neuron 1n, a synaptic cell (СЯ), and controlled linear voltage generator (УГЛН) and works as follows. Signal $y'(t)$ is fed in the form of an inhibiting link from the output of differentiating neuron P to the input of neuron 1.1. A linearly growing signal from the controlled linear voltage generator goes to the stimulating input of this neuron. When the stimulating signal is slightly greater than the inhibiting signal neuron 1.1 produces the first pulse at its output, which resets the linear voltage of the generator at 0. After the voltage is clear the process is repeated again. Time interval T between successive voltage resettings depends on the magnitude of the inhibiting link and the steepness of its characteristic k. For cell 1.1 it is $T = y'(t)/k$, while the frequency of pulsation of neuron 1.1 is $f = k/y'(t)$. Feeding an output signal of this frequency through synaptic weight $1/k$ to the stimulating input of the synaptic cell with a controlled amplification coefficient together with signal $y(t)$, we receive the first differential relation d_0. The other first-layer cells work in a similar fashion, singling out the first differential relation.

It should be noted that coefficient k is selected on the condition $k \geqslant 10$ in order to reduce error in obtaining the quantity $d_0, \ldots, d_n$.

The second differential relations are computed by the second layer of neurons. The computation operation and work of the neuron structure are similar to those presented above. Change in the coefficients of the transfer function of the control system owing to a worsening of the operator's reaction causes change in the system reaction, which in this case is described by an exponential polynomial. Then the second relations will not be constant quantities, but rather functions of time. Upper and lower limits on change in time functions of the second relations are set for the normal operator state. The second differential relations calculated, which have upper and lower limits, are fed to the third

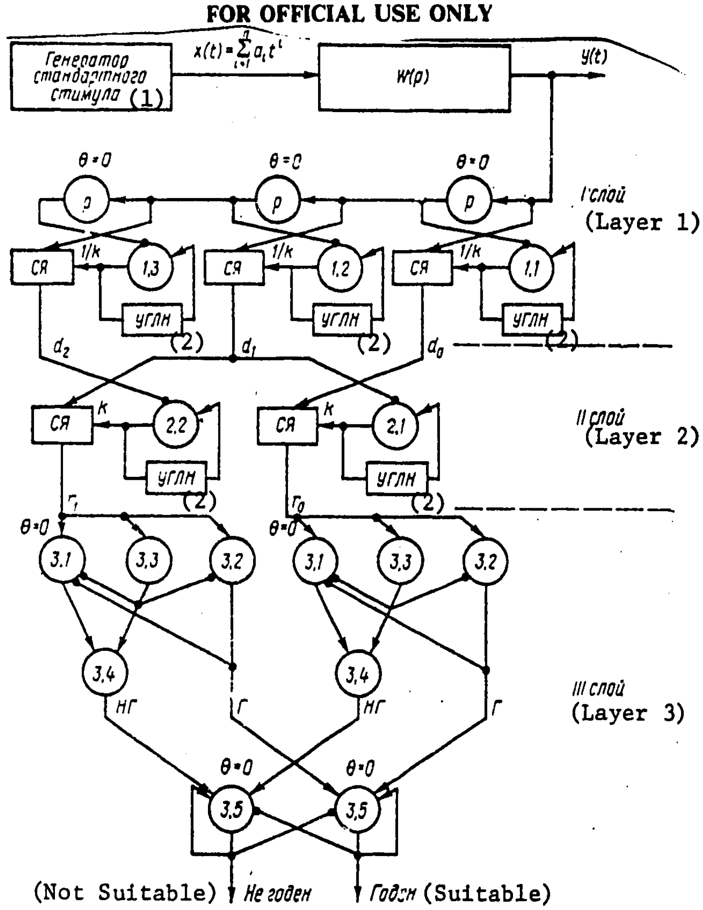

Figure 76. Flowchart of Neuron Device for Admittance Monitoring of the State of the Operator.

Key: (1) Standard Stimulus Generator;
(2) Controlled Linear Voltage Generator.

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layer of neurons, which is a set of neuron comparators for each r_i described in work [35]. Each of the neuron comparators produces a "suitable" or "not suitable" signal. These signals converge on summing neurons 3 and 5, which perform the "OR" operation.

When the values of the second differential relations go outside the upper or lower limits, neuron 3.5 of the "not suitable" channel is triggered, "stimulated" by the positive feedback, and sends a strong inhibiting link to neuron 3.5 of the "suitable" channel.

Thus, the output signal of the "man-machine" system is analyzed by juxtaposing functional relations and comparing their current values with nominal values corresponding to proper working state of the system.

The proposed monitroing methodology was tested on a system described by a second-order equation and set up on an EMU-10 analog machine. The results of experimental studies confirmed the effectiveness of this methodology, which permits the following:

a. monitoring the dynamic characteristics of the system;

b. precluding the possibility that the system will go into a dangerous regime by analyzing the process at the front and switching the system off in emergency situations;

c. identifying the weight and impact of the monitored parameters on the transitional process of the system.

Chapter 7. The Fundamentals of Building Complex Bioelectronic Systems

When studying the psychophysiology of the operator in extreme conditions and considering the further development of methods of normalizing the human state in these conditions, we must look at research on questions of self-regulation in the nervous system and methods of active influence on the brain.

P. V. Bundzen, N. P. Bekhtereva, and Yu. L. Gogolitsyn [1] note that the distinctive feature of the neurocybernetic approach to studying the functions of controlling biological systems, including the study of regulatory functions of the central nervous system, comes above all in the attempt to give an algorithmic description of the processes of self-regulation. In this case, as Fitsner correctly emphasizes [2], a knowledge of the algorithms of functioning of biological control systems is necessary not only to physiologists, but also to specialists of technical automatic control systems. Studying the algorithms of normal and pathological regulation of functions is even more important for purposeful organization of the processes of optimal biological control and compensation for impaired brain functions.

For this reason it is especially timely to use automatic control theory for quantitative analysis of the processes of adaptive regulation in the central nervous system [3-5].

As Grodings has pointed out [6], however, the use of known methods of analyzing technical automatic control systems in the study of biological control systems, especially the regulatory systems of the cerebral cortex, is extremely complicated. The primary reason for this is the hierarchical and dynamic nature of the functional brain systems, which are constantly influenced by many external and internal receptors. As a result, it is extremely complex to achieve even a temporary stabilization of the functional state for testing the regulatory characteristics of neurodynamic systems.

Here we encounter the problem of self-regulation of the nervous system, in particular of the cerebral cortex, its highest part. This problem is presented in sufficient detail in the literature (see for example [5, 11, 12]).

The structural foundation of the processes of self-regulation is the closed system of connections among distinct subsystems of the central nervous systems of living organisms and the fluctuating character of physiological activity [5-12].

The problem of control and self-regulation in the living organism was widely discussed in light of the ideas of cybernetics, above all the principle of feedback [7, 13, 14].

O. Zager [15], reviewing the mechanisms of self-regulation in cortical-subcortical relationships, points out that cortical-subcortical regulation of inhibition and easing the corticofugal tract are accomplished by the influence of the cortex on the subcortical centers. The activity of the latter is "modeled" depending on information received by the cortex along specific and non-specific paths. P. V. Bundzen [16], using the methodology of electroencephalography with automatic frequency analysis and automatic autostimulation in the rhythm of oscillations of the envelope of alpha activity, is also inclined to accept the leading role of cortical structures in organization of the auto-regulation process directed to finding and maintaining optimal dynamic characteristics of cortical neurons (their excitability and work capability).

Ye. Ya. Voytinskiy and V. Ya. Pryanishnikov also used the electroencephalographic methodology to employ the techniques of technical cybernetics in neurophysiology [17].

Analysis of the averaged elicited responses to electrical stimulation of the cortex from the standpoint of automatic regulation theory made it possible to view the cerebral cortex as a population of inhibition and stimulation neurons among whom connections are determined by the time constant of the neuron chain and the amplification factor of feedback. Linear differential equations with variable coefficients, in the opinion of many investigators, permit establishment of a correlation between the activity of a single neuron and the evoked responses, between the electroencephalogram and behavioral activity. It has been established that asymmetry in the length of the phases of oscillations of potential in the electroencephalogram plays a certain part in the mechanisms of brain self-regulation [18]. Yu. A. Budonis, studying the average amplitude of the electrocorticogram of animals, its frequency characteristics, spectrum of output, and average value of extremes for 10 seconds of the process, found that during adaptation the nervous system is constantly changing its functional level and, carrying on the search like a self-adjusting system, tries to find the most optimal work regime to match the existing situation.

Flory and coauthors [19] consider it possible to introduce the concept of neuropsychic homeostasis as a dynamic equilibrium of psychophysiological processes, and in particular the concept of the existence of certain mechanisms that guarantee constancy of mental activity under conditions of the constant influences to which a normal organism is subjected.

Attempts have been made recently to reflect the complexity of biological automatic regulation systems more accurately. Thus, G. I. Polyakov [20] identifies six functions to which distinct anatomical-physiological mechanisms correspond: regulation and self-regulation, monitoring and self-monitoring, and control and self-control.

The sphere of self-regulation comprises systems that maintain a constant internal environment. Self-monitoring is carried on by analyzer-coordination mechanisms of the cerebellum and upper "dvukholmiye" [double mound] of the middle brain types.

Monitoring involves the influences which the analyzer systems exert on self-monitoring reflexive adaptations; self-control involves the forms and components of behavior whose programs are worked out over the life of the species (instinctive reactions). Finally, G. I. Polyakov uses control to mean both "free" or arbitrary (in human beings conscious) control and automated (in human beings unconscious) control.

G. V. Voronin [21], emphasizing that the theoretical foundation of the investigation of complex dynamic systems is the structural approach, believes that the consideration of biological systems should proceed as follows: break the complex system down into elementary elements by successive division at points of application of control actions; classify the elementary elements only by their dynamic characteristics; the dynamics of the elementary elements should be described by differential equations of no greater than the second order. As examples of elementary elements the author identifies receptor cells, motor neurons, and afferent neurons.

V. M. Khayutin [22] made a detailed study of the need to use the principle of regulation related to disturbance using the example of the regulation of blood circulation. He points out that this was done by A. A. Ukhtomskiy in 1938 with respect to the nervous system [23]. Indeed, Ukhtomskiy criticized the "biased description of the reflex instrument as a mechanism to reject and eliminate environmental influence on the organism," noting that "it is easy to become one-sided if we picture the apparatus of reflection as a kind of giant mirror" [23]. V. M. Khayutin believes that regulation based on deviation is inefficient; a regulator working on this principle can only eliminate a harmful effect after it has been permitted. Pointing to Poncelet's principle, he remarks that analysis of the mechanisms of the vasomotor reflexes from tissue receptors makes it possible to establish the step-by-step inclusion of the effector organs involved in the vasoconstrictive effect as the stimulus grows stronger. In other words, the vasodilation loads are compensated for by reflex constriction of the vessels of other organs. Even when analyzing such a limited system as the isolated part it is possible to identify traits of a combined control system (N. M. Amosov and others [24]).

Since 1968 we have been developing views of the brain as a combined control system (for greater detail see work [5]). This is one of the aspects of fundamental research in the field of neurobionics.

One of the most important objectives of neurobionics is to move from the analog principle of modeling to the composition method, to creation of systems that include living and manmade elements.

Formally speaking, beginning from the functional role of the living organism in the full contour of the organism, the bioelectronic systems generally can be divided into two classes: (1) those in which the organism or its subsystem is the object of regulation of a technical device; and (2) those where the organism or its subsystem regulates a technical device [25].

With respect to the system the statement of J. Delgado is striking: "In the near future 'stimosivery' — people with feedback between neurons and technical equipment — will become a significant element in the 'man-computer' system."

The term "medical system" is used today for the first class. We will designate the second class "biotechnical system."

This division is just as arbitrary as the division into the object of regulation and the regulator, and refers more to the objective of setting up the particular system, whereas the difficulties of realizing them are common.

It is possible to identify these fundamental problems on the road to solving these questions:

a. evaluating the state of the biological object on the basis of analysis of a set of physiological signs;

b. studying the dynamic characteristics of change in physiological factors influenced by a set of external actions.

Intensive research has been underway for some time in the first area and there are already many works devoted to this problem. With it, moreover, it is often possible to achieve precise formalization which, in turn, permits broad application of mathematical methods of establishing algorithms for the process of evaluating the state of the organism according to a given set of signs.

At the same time, the second problem, in precisely that formulation which is dictated by the objectives of control or stabilization, is comparatively new. And here, in turn, there arise a whole series of issues which go beyond the framework of the present book.

Our further presentation will deal with the questions of realizing and employing biotechnical systems.

Biotechnical systems, in particular neuroelectronic systems, can be used as a tool to study the work of the brain, on the one hand, or, on the other hand, to build devices to control industrial processes when it becomes necessary for an automatic backup unit to take over the functions of an emotionally disturbed operator, to optimize training processes, and finally, to develop new automatic recognition and tracking systems with due regard for the patterns identified during study of the human brain.

Consideration from certain general standpoints of the full diversity of instruments and systems that include a biological object as a functioning element can conveniently use a flowchart that reflects the purposeful behavior of an organism in an environment (see Figure 77 below). The flowchart reflects the case where a biological object, influencing a local segment of the environment, is attempting to achieve a definite goal. The concept of "environment" here is used in the broad sense and may include both natural surroundings and some technical system. Input 1 of the nervous system is the channel along which

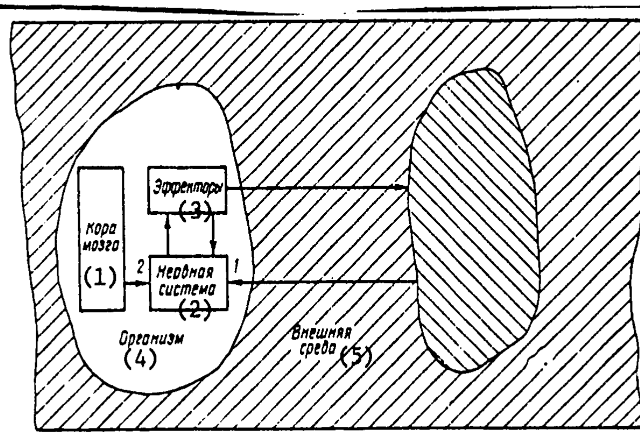

Figure 77. Flowchart of Purposeful Behavior by Organism.

Key: (1) Cerebral Cortex;
(2) Nervous System;
(3) Effectors;
(4) Organism;
(5) Environment.

information on the state of the environment arrives. The signal from the block which we have arbitrarily called "cerebral cortex" and which serves to assign the goal (motivation) of behavior goes to input 2. The purpose of including this block in our consideration is to in some way differentiate the functional activity of the nervous system in the performance of vegetative functions, which continues in an anesthetized organism, for example, from purposeful behavior in the environment. There is no need here to consider all the many ways of assigning the signal at input 2. They depend on many factors, including the phylogenetic level of the organism. It is also unimportant for our further discussion whether the signal is formed at this input under the influence of external factors or endogenic factors. The only important thing to emphasize is that the existence of this input is an essential condition for purposeful behavior by the biological object.

Because when we consider the flowchart (see Figure 77 above) we are not stipulating the specific nature of the living organism, the "cerebral cortex" block means a certain brain mechanism which assigns the direction of action and is switched off in a definite physiological state, for example systemic inhibition.

Depending on the functional load of the biological object biotechnical systems can be preliminarily divided into the three following classes:

1. systems of the "bottom" level of complexity where the biological object is used as a "sensor" for the technical device;

2. systems of the "intermediate" level of complexity where one (or several) homeostatic regulators of the living organism are used for control purposes;

3. systems of the "highest" level of complexity, using purposeful behavior by the biological object.

Let us consider each of them separately.

1. In this case we receive a system without direct feedback to the biological object, and regulation of the technical device takes place on an open contour. A flowchart of this is shown in Figure 78 below. One or a whole set of

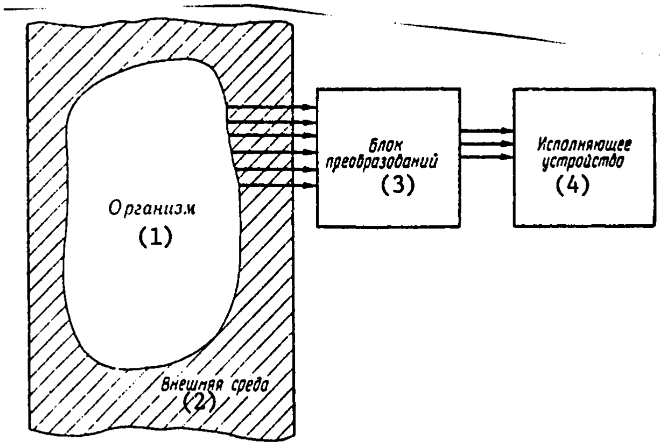

Figure 78. Bioelectronic System with Open Contour.

Key: (1) Organism; (2) Environment; (3) Conversion Block; (4) Actuating Unit.

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electrograms of biophysical or biochemical factors by the organism which reflect changes in physiological organs is used as control signals for external devices. Examples are the attempt to use the eye as a sensor of the angle of direction for an automatic sight (based on the reflecting characteristics of the cornea), the use of a fly to analyze gas composition, or biocontrol manipulators. It must be noted that the term "sensor" is used in the broad sense, in other words we allow the existence of local feedback, for example proprioceptive, in the use of motor output. In this case the external unit becomes a kind of part of the organism, enlarging its physical capability.

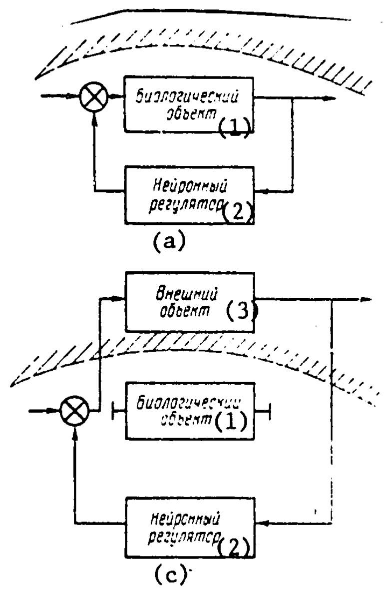
This class of biotechnical systems is purely machine-like and lacks the basic advantages of biological organization; in other words, they are systems which, once established, possess no other qualities but those which were designed into them. The use of a biological analyzer, for example, to recognize images is equivalent to replacing the problem of direct recognition with the scarcely more simple problem of recognizing the state of the brain's neuron system. This applies to the problem of using the full range of functional characteristics of a biological analyzer, because if we are speaking of using only a natural receptor to find a certain fixed sign, this problem can usually be solved by purely physiological techniques. For example, a conclusion can be drawn relative to the position of a straight line in the field of vision on the basis of an analysis of the biopotentials of the retina, and Pribam showed that it is possible to establish which set of images is in an animal's field of vision by the pattern obtained by taking multiple electrical readings from the visual area of the cortex of a monkey. But we are considering a fixed, limited set of signs which can also be established by technical means. Therefore, the use of such a biotechnical system can be justified on the condition of short-term work and strict economic requirements or with limited weight and volume.

The main difficulty of realizing this class of systems lies in solving this problem, and it is only by solving it that a decoding block can be synthesized (see Figure 78 above).

2. A number of interesting works involving quantitative description of the pupillary reflex, the oculomotor function, maintaining and controlling body temperature, and the like have been devoted to organism regulatory systems on the "intermediate" level of complexity. These homeostatic systems, which are the foundation of the vegetative functions and unconditioned reflex activity of a biological object, are a convenient object for investigation because they can be considered with fairly good approximation as independent subsystems of the organism. Figure 79a shows a flowchart of this type of biological regulator in the general case, where the inputs and outputs are vectors of fairly large dimensionality.

It is obvious that the problem of realizing this class of biotechnical systems can be solved in two ways: when the technical device is connected in parallel to the biological object of regulation (Figure 79b) and when the technical device is connected in place of the biological object of regulation (Figure 79c). In the first place parallel connection (we are disregarding the questions of physiological methodology because they are dictated by the actual content of the task) leads to a change in the nature and quantity of input information of the biological regulator and, consequently, to a change in the functioning of the entire system. (Figure 79 a, b, and c below.)

In a number of cases here it would be possible to figure on the plasticity of the nervous system and a corresponding reorganization of the functional architecture of the nerve apparatuses, although there is every reason to think that this property of plasticity is fairly limited. But for normal work by the system (see Figure 79b) it is also necessary that the dynamic characteristics of the external object correspond fairly well with the dynamic characteristics of the biological object.



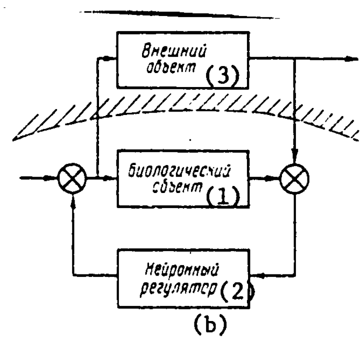


Figure 79. Bioelectric Systems of the "Intermediate" Level of Complexity.

Key: (1) Biological Object;
(2) Neuron Regulator;
(3) External Object.

The requirement of a fairly small difference in dynamic characteristics also remains in force in the second case. Here too we will not dwell on the difficulties of physiological methodology, which are furthered by the fact that it is not always possible in a living organism to draw a clear line between the object of regulation and the regulator.

From a formal point of view both problems are equivalent to the following situation: there is a regulator with a definite range of change in parameters (determined, for example, by the plastic properties of the nervous system) and it is necessary to select an object with dynamic characteristics lying in the appropriate range. It is obvious that this statement of the problem becomes less meaningful when the boundaries of this range are narrower.

Everything stated above gives reason to exclude the class of biotechnical systems of the "intermediate" level of complexity from consideration in an applied, bionic aspect. At the same time, the systems are extremely important as an object of experimental research because they allow a closer approach to formalization and quantitative evaluation of certain physiological concepts such as plasticity of the nervous system and self-regulation of the cerebral cortex. In addition, it is especially important that this field stimulates study of dynamic characteristics and the laws of conversion of information in different functional systems of the organism.

3. This class includes above all systems involving participation by a human operator. The necessity of operator participation in the work of automated systems follows directly from the limited capabilities of contemporary means of automation, and at the same time the operator often becomes the "bottleneck," limiting the speed and efficiency of the system as a whole. An example of a solution with differing types of complexity is a proposal to use pigeons to guide intercontinental ballistic missiles to the target.

One of the devices designed for special training of animals is the Skinner box, named after the man who developed it.

In 1964 American scientists conducted a series of experiments to investigate the formation of complex visual images in pigeons. In the course of the experiments the birds were shown slides in which a human image was camouflaged by trees, motor vehicles, window frames, and the like. These experiments, which also investigated the questions of categorization and sorting of elements of an image, provide proof of the possibility of animals' forming fairly general visual images.

We may also mention the experiments of Verkhev. He was working as a psychopharmacologist in a large pharmacological company and suggested using pigeons for quality control. The company produced pills (gelatin capsules containing medicine), and monitoring their quality by conventional methods, that is discarding "empties," damaged capsules, and the like, demanded enormous expenditures with a production volume on the order of 20 million pills a day.

The fundamental drawback of biotechnical systems using purposeful animal behavior is that they are limited to fixed, predetermined objectives. This is a result of the limited assortment of means of influencing the brain for the purpose of fixing the necessary "signal" at output 1 (see Figure 77 above).

It is difficult to predict today whether systems using purposeful animal behavior will find application. The only thing that can be said with confidence is that building them and experimental study of them are justified for several reasons. In the first place, this will promote formalization, and consequently also quantitative evaluation of such concepts as the complexity of purposeful behavior, whether from the standpoint of information theory or using an evaluation of the logical depth of sequentially performed operations by some other technique. In the second place, the search for direct, effective ways to influence the animal brain to assign some particular character to purposeful behavior [Russian text incomplete at this point].

The results obtained are important both for building diagnostic and therapeutic medical systems and for improving the symbiosis of man and machine. We do not mean here just the development and construction of systems that insure stabilization of a given physiological state of the human operator, but also normalization of the mental state of the operator. At the present time the latter problem is far from solution. It is being held back by difficulties on both the technical and psychophysiological levels (searching for effective ways to purposefully influence the brain and mental activity) and moral factors. But the high cost of operator errors and its tendency to increase sharply in the future force us to ponder this problem.

We can conclude from the discussion above that in the applied aspect the most timely biotechnical systems are two types:

a. systems where the biological object is used as a sensor;

b. systems which use purposeful behavior of a living organism.

We should remark that the problem of what is called "cyborgization" of the human and animal, that is, developing functional artificial organs and systems for them, belongs to this class of problems. Properly speaking, already today when artificial heart pacemakers are working in the human organism and attempts are being made to devise artificial hearts, blood vessels, tracheas, digestive tracts, joints, and tendons, cyborgization is already beginning. In the United States alone 250,000 persons have artificial organs in their bodies. We are confident that in the next 15-20 years the world will witness successful development of artificial replacements for distinct segments of the central nervous system, and in the year 2000 cyborgization will acquire the necessary scope. For example, already today successful attempts are being undertaken to give sight to the blind.

Works have appeared in recent years which investigate the general principles of information processing by the cerebral cortex with the objective of building neuroelectronic systems. In such systems the brain (as control unit) and a technical device function together. Attempts to automate regulaion of the state of anesthesia belong here. This is an important task in practical medicine.

It appears possible to use the electrical signals of the brain and information on the state of the cardiovascular and respiratory systems to begin designing an instrument that automatically regulates the feeding of anesthetic to the human organism. There are also systems to regulate blood pressure and respiration by means of biopotentials. Heart biopotentials are used to control X-ray equipment, blood circulation, and the course of a thoracic operation, to engage an electrical stimulator, and for other purposes. Another example of a neuroelectronic system is the use of the smooth motor system to control the movement of a technical object (for example, some manipulator working in a "hot" chamber [12, 26, 27]).

After numerous studies in the USSR and abroad, experiments with the use of feedback provided new impetus in studying the mechanisms of self-regulation and controlled change in definite organism functions. It was demonstrated that test subjects in experiments with feedback that informed them of the results of activity improve the precision of motor acts significantly and learn more rapidly. Moreover, the test subjects can monitor the frequency spectrum of their own EEG if they receive visual or aural feedback on the results of this monitoring.

Studies have shown that under conditions of biological feedback an epilepsy victim learned to monitor epileptic attacks and suppress them by intensifying his sensomotor rhythm.

Thus, we have come to understand the possibility of using the biological feedback of the EEG to study the interrelationship between the behavior of a test subject and change in the subject's EEG. Primary attention in these experiments was devoted to studying the possibilities of regulating the Alpha rhythm, although works have appeared recently devoted to operant learning using Beta activity of the EEG. The usual methodology in these studies is to give the test subject light or sound signals when certain pictures of bioelectric activity appear in the EEG. The inclusion of feedback (stimulation) depends on the level of the triggering threshold, which is set by the experimentor.

We have also conducted such experiments. The system represented in the flowchart in Figure 80 below was tested in our laboratory. It is designed to maintain an optimal speed of presentation of visual information for various states of the human operator. The criterion of optimality in this case is the efficiency of

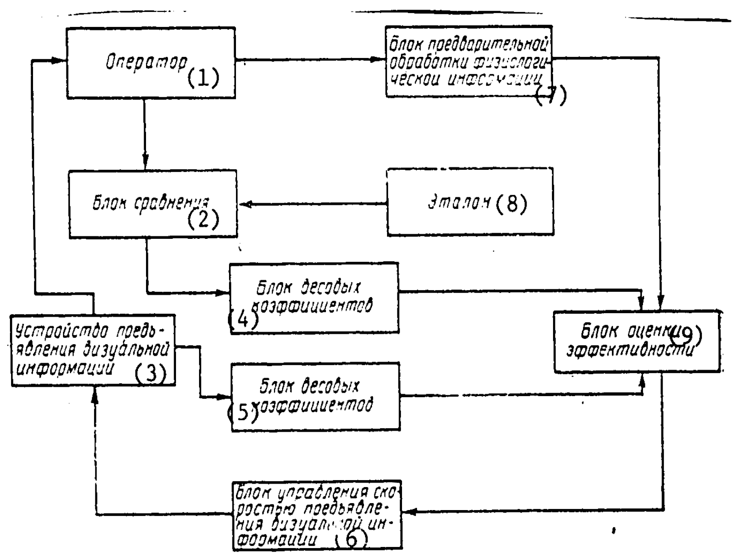


Figure 80. Flowchart of Neuroelectronic System Developed in the Division of Neurobionics.

Key: (1) Operator;
(2) Comparison Block;
(3) Unit To Present Visual Information;
(4) Weighted Coefficient Block;
(5) Weighted Coefficient Block;
(6) Block To Control the Rate of Presentation of Visual Information;
(7) Block for Preliminary Processing of Physiological Information;
(8) Standard;
(9) Block To Evaluate Efficiency.

operator work, which is determined by the amount of input information processed and the number of mistakes made. The system is tuned by showing a test tape where the operator's answer is compared with a standard and the comparison unit issues an error signal when the answer deviates from the standard.

Signals on the rate of movement of the tape and the existence of an error go to the efficiency evaluation block through the weighted coefficients block. The values in this block are determined on the basis of a preliminary analysis of the nature of operator activity.

The efficiency evaluation block is realized on an analog computer. The block to control the speed is a linear servo-amplifier.

Further work by the system showing random visual information is done with an open feedback loop for errors. This is possible because the efficiency of activity (as defined above) changes only slightly within the range of regulation of the speed of presentation of visual information related to change in the state of the operator.

In the process of development a discrete variation of the system to control the rate of presentation of visual information is found where the moment of change in frames is computed on the basis of an evaluation of the ratio of the outputs of the Alpha and Beta rhythms. This criterion has different values for different types of activity depending on the "cost" of errors and coefficients that determine the "cost" of the total amount of information processed. Thus, the device to evaluate the efficiency of the system forms a control signal that maximizes the total "cost" of operator activity in the system.

The physiological mechanism on which the system is based is the following: in a state of rest the output of a person's Alpha rhythm in the EEG spectrum is greater than in a state of random mental activity. Thus, the appearance of an information picture on the screen causes a sharp decline in the output of the Alpha rhythm in the EEG spectrum of the operator which then grows as the operator resolves the experimental visual information (end of processing). With respect to the Beta rhythm, in general the opposite relationship is observed.

Based on this physiological mechanism, the preliminary processing block includes an encephalograph, a narrow-band active filter to single out the Alpha rhythm component, a linear amplifier, a detector, and an integrator with a regulated time constant. Because of change in the conditions of taking the encephalogram for each concrete case and its individual character (in particular the distribution of energy in the spectrum by frequencies), this block envisions preliminary regulation of amplification.

Methodologically speaking, the visual information is presented in the form of a picture with an assignment that is projected on the screen by a film projector. The rate of feeding of visual information is regulated by regulating the rate of movement of the film in the projector (where each frame of the test film has the same information content). It has been reported in the press that the scientific research administration of the U. S. Navy has concluded a contract with a certain company to investigate the possibility of controlling weapons systems or other mechanical systems "by thinking about them." Another example is prostheses which are controlled by electrical signals from the muscles.

In practice there is a tendency to use systems of the first and second types discussed above together. An example of such a combination is the work of V. M. Akhutin [28], which discusses the questions of evaluation and stabilization of a given physiological state of a human operator. In this sense, setting up certain biotechnical systems of the first type, for example biocontrolled manipulators, is by no means a goal-in-itself, but rather aims at broadening the area of purposeful behavior. Independent control contours are formed by this kind of composite use of systems of the first and second types. Thus, the flowchart shown in Figure 81 below differs from that given in Figure 75 (above) by the addition of two blocks. The conversion unit analyzes the functional state according to

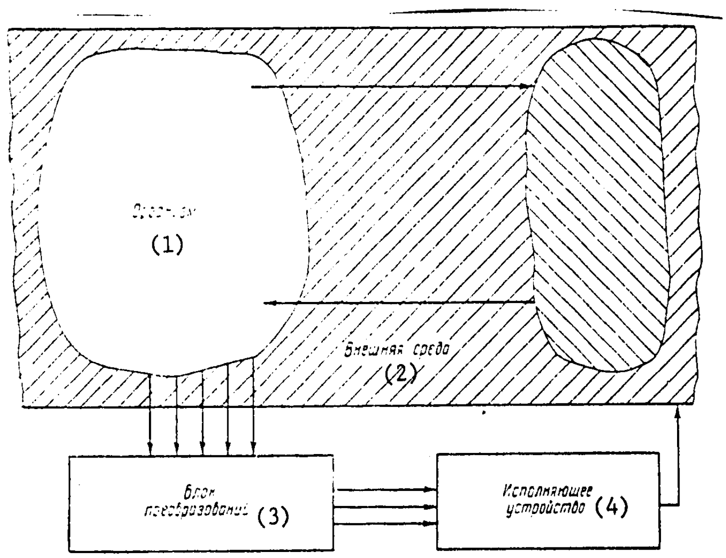


Figure 81. Composite Bioelectronic System.

Key: (1) Organism; (3) Conversion Block;
(2) External Environment; (4) Actuating Unit.

an assigned algorithm and set of electrograms and outputs a signal to the actuating unit. The concrete nature of the particular external units, of course, is determined by the purpose of the additional regulation contour. In particular, it may be viewed as a unit to monitor or rescue the human operator. Then the block, converted on the basis of an evaluation of physiological information, should output a signal to the actuating block of the unit calling for the human being to be rescued or switched out of control.

When solving the problem of building neurotechnical systems, of course, the job arises of thorough analysis of the electrical signals of the nerve structures and of excited structures in general (the "interface" of living and nonliving systems at the present time can only be conceived of in electrical terms).

Soviet scientist P. V. Simonov and F. Ye. Temnikov believe that in the future adaptive bioelectronic systems will find application for studying the rules that govern human or animal perception of sense images and signals with an emotional coloring in order to build devices that maintain the attention of a person in the control of industrial processes where, when critical situations occur, the functions of a disoriented operator must be taken over by an automatic device; to optimize the training process (development of teaching machines capable of considering the emotional impact of the learning material); and finally, for the development of new automatic recognition and tracking systems that take account of patterns revealed during the study of analogous human activity.

Neuroelectronic systems can also be used to study brain functions. Thus, at the Institute of Experiment . Medicine of the USSR Academy of Medical Sciences P. V. Bundzen and others [29] were able to take a new step forward in understanding the processes of autoregulation of the brain by controlling the oscillations of the Alpha rhythm using a photostimulator. Their studies offer precise recommendations for creating optimal conditions and for selection of operators. In this respect, the research of A. M. Zingerman, D. N. Menitskiy, and L. S. Khachatur'yants [30], associates at the same institute, is instructive. On the basis of data in the literature and studies conducted under laboratory conditions and in space flight, they used one of the modifications of bioelectronic systems and reached interesting conclusions on defining the "quality" of operators, in particular the "predisposition to accidents."

On the basis of generalization of domestic, foreign, and his own experience, the author proposes the following classification of bioelectronic (neuroelectronic) systems.

Class A. Passive Systems:

1. Study of psychophysiological indicators to diagnose and predict the state of humans and animals in different (including extreme and pathological) conditions using technical equipment to process and display information. Construction of various levels of monitors to automate the collection and processing of information on the state of human and animal organisms, above all the mental state;

2. The use of biological systems as sensors (optical, aural, and tactile) for technical systems. Construction of systems that use biophysical and biochemical test signals on the state of the organism based on physicochemical and biological principles;

3. The use of the resources of theoretical and technical cybernetics to study the brain ("antineurobionics").

Class B: Active, Adaptive Systems:

1. Use of the principles of negative and positive feedback and self-regulation for purposeful study of and influence on various systems of the organism, above all the brain. Determination of ways to use the "latent reserves" of the central nervous system. Self-control of the functional state of the central nervous system;

2. Construction of neurobionic systems for the purpose of normalizing and intensifying the activity of the human operator and eliminating pathological states of varied etiology (mental disorders; delaying the action of poisons, shock-causing factors, and ionizing radiation; anesthesia, hypnosis, and so on). Control of the organism using dynamic models of brain activity and the electrical activity of "active points" on the body surface;

3. Searching for new forms of building hybrid bionic systems that use the purposeful behavior of living organisms (in particular, stimulation of "start" and "stop" zones) for contact or telemetric control of technical devices;

4. "Neurocyborgization" (morphofunctional prosthesis of the nervous system).

Thus, we have considered some basic ways to build neuroelectronic systems applicable to the problems of the psychophysiology of the human operator.

Appendix 1. Program of the Simulation Psychophysiological Model of Operator Activity.

```
 INTEGER AA(24,50),IU(4),IV(4,50),NSM(4),
*NEM(4),NEMI(4).MTZ(8),IYC(4)
 INTEGER I180(4)
*,NEMM(4),NEMIN(4),NSMM(4)
*,NP(4)
 СЛЕДУЮЩИЕ ПЕРЕМЕННЫЕ — ВЕЩЕСТВЕННОГО ТИПА
 REAL T(4),TI(24,50),M(4),F(4),TU(4),TP(4),TA(4),
*SN(4),SY(4),BB(4),GK(4),TPR(4),SM(4),SK(4),CK(4),
*TAZ(4),PR(4),EM(4),EMK(4),EMI(4),KIJ,SS(4)
*,MJ,MJ1,IIJ,TC(4),TPN(4),TPNS(4)
 REAL TSR(4),TPRS(4),TCS(4),SMS(4),SKS(4),
*EMM(4),EMIN(4),ES(4),PRS(4),TAZS(4),
*NC(4),SMM(4),CKS(4),EMIS(4),EMKS(4),
*EMS(4),HP(4,50),HE(4,50),THE(4,50),PH(4,50),
*BZP(4,50),SPH(4,50),SC(4,50),NHE(4,50),
*POS(4,50),SSY(4),SSN(4),APP(4),SCP(4)
 COMMON NAA,NTI,N,NA,NO,ITI,NP,NПРОГ,IMAX,
*T,M,F/K/TI,AA,PR1,PR2,PR3,PR4,PR5
 COMMON /U/U1,U2/R/R3/KI/KIJ
 DATA MTZ(1),MTZ(2),MTZ(3),MTZ(4),MTZ(5),MTZ(6)
*/30HJJJJJEEEEEDDDDDCCCCCHECУЩCУЩEC/,MTZ(7),
*MTZ(8)/10HНЕУД.УСПЕХ/
 COMMON /Q/NY,PRY,TIBS,NC,SSY,SSN,APP,PRS,
*TSR,TCS,TPNS,TAZS,TPRS
 COMMON /B/SMM,NSMM,SMS,SKS,EMIN,NEMIN,EMM,
*NEMM,
*ES,EMS,EMIS,SCP,CKS
 DATA IYC(1),IYC(2),IYC(3),IYC(4)
*/ 20HУСПЕШНО, НЕУДАЧНО. /
 CALL СПЕЦ(ЗАКР,ВК1,ПЧ1)
 U1 = 3.1415926
 U2 = 0.5420887
 ВВОД ДАННЫХ
 NПРОГ = 0
```

[Continued, next page]

```
10 CALL POINT
   CALL СПЕЦ(ОТЫ,В,ПЧ1)
   НАЧАЛО ПРОГОНА
   IT = 0
   NY = 0
   TIBS = 0.0
   DO 30 J = 1,NA
   TPN(J) = 0.0
   TSR(J) = 0.0
   TPRS(J) = 0.0
   TCS(J) = 0.0
   SMS(J) = 0.0
   SKS(J) = 0.0
   EMM(J) = 0.0
   EMIN(J) = 0.0
   ES(J) = 0.0
   PRS(J) = 0.0
   TAZS(J) = 0.0
   NC(J) = 0.0
   I180(J) = 0
   SMM(J) = 0.0
    CKS(J) = 0.0
   SSY(J) = 0.0
   SSN(J) = 0.0
   SCP(J) = 0.0
   EMIS(J) = 0.0
   EMKS(J) = 0.0
30 EMS(J) = 0.0
   DO 31 J = 1,NA
   DO 31 I = 1,IMAX
   HP(J,I) = 0.0
   HE(J, I) = 0.0
   THE(J, I) = 0.0
   PH(J,I) = 0.0
   BZP(J,I) = 0.0
   SPH(J,I) = 0.0
   POS(J,I) = 0.0
   SC(J,I) = 0.0
31 NHE(J,I) = 0.0
   НАЧАЛО ИТЕРАЦИИ
   УСТАНОВКА В ИСХОДНОЕ СОСТОЯНИЕ ДЛЯ РАССМОТРЕНИЯ
   1 ПОДЗАДАЧИ
42 DO 40 J = 1,NA
   TU(J) = 0.0
   IU(J) = 1
   TA(J) = 0.0
```

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[Continued, next page]

```
      TP(J) = 0.0
      GK(J) = 0.0
      SN(J) = 0.0
      SY(J) = 0.0
      BB(J) = 1.0
      TPR(J) = 0.0
      SM(J) = 0.0
      NSM(J) = 0
      SK(J) = 0.0
      CK(J) = 0.0
      TAZ(J) = 0.0
      SS(J) = 0.0
      PR(J) = 0.0
      DO 40 I = 1,IMAX
   40 IV(J,I) = 0
      DO 43 J = 1,NA
      EM(J) = 0.0
      NEM(J) = 0
      EMI(J) = 0.0
      NEMI(J) = 0
      TC(J) = 0.0
      НАЧАЛО ИТЕРАЦИИ ОЧЕРЕДНОЙ ПОДЗАДАЧИ
   43 EMK(J) = 0.0
      IT = IT + 1
   52 JD = 0
   45 J = 0
      KI = 0
      TM = 1000000.0
      DO 50 J1 = 1,NA
      T1 = TU(J1)
      IF(IU(J1))54,54,55
   54 KI = KI + 1
      GOTO 50
   55 IF(J1 - JD)53,50,53
   53 IF(T1 - TM)51,50,50
   51 TM = T1
      J = J1
   50 CONTINUE
      IF(KI - NA)65,222,222
      I - НОМЕР ПОДЗАДАЧИ, КОТОРУЮ НАДЛЕЖИТ ВЫПОЛНИТЬ
      ОПЕРАТОРУ J
   65 I = IU(J)
      ПРОВЕРКА D/I1,J1/
      I1 = AA(NA + NA + J + J - 1,I)
      J1 = AA(NA + NA + J + J,I)
      ЕСЛИ I1*J1 = 0, ТО УСЛОВНОЙ ЗАДЕРЖКИ НЕТ
```

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```
   IF(I1*J1)61,60,61
61 IF(IV(J1,I1) — 2)62,60,60
60 CONTINUE
64 IIJ = TI(J,I)
   DX = IIJ — TU(J)
   IF(DX)70,70,71
62 JD = J
   GOTO 45
71 TU(J) = IIJ
   TP(J) = TP(J) + DX
   GOTO 52
   ВЫПОЛНЕНА ЗАПИСЬ ПРОСТОЯ
   ПРОВЕРКА ТИПА J
70 IF(AA(NA + J,I) — 2)80,72,80
   СИНХРОНИЗАЦИЯ ВРЕМЕН TU
72 TM = 0.0
   DO 73 J4 = 1,NA
   DX = TU(J4)
   IF(DX — TM)73,73,74
74 TM = DX
73 CONTINUE
   DO 75 J4 = 1,NA
   75TU(J4) = TM
   ВЫЧИСЛЕНИЕ ВРЕМЕН TN И TE
80 TN = 0.0
   TE = 0.0
   DO 81 I4 = 1,IMAX
   IF(IV(J,I4))82,82,81
82 DX = TI(NA + J + J — 1,I4)
   IF(AA(J,I4))84,83,84
83 TN = TN + DX
   НЕСУЩЕСТВЕННОЕ ВРЕМЯ TN
   GOTO 81
84 TE = TE + DX
   ВРЕМЯ ВЫПОЛНЕНИЯ СУЩЕСТВЕННЫХ ПОДЗАДАЧ TE
81 CONTINUE
   ОСТАВШЕЕСЯ ВРЕМЯ = TAS
   TAS = T(J) — TU(J)
   IF(TAS)94,94,93
94 SIJ = M(J)
   IF(AA(J,I))92,92,102
93 IF(TAS — (TN + TE))90,91,91
91 SIJ = 1.0
   НАПРЯЖЕННОСТЬ РАВНА 1
   GOTO 102
   ОПРЕДЕЛЕНИЕ СУЩЕСТВЕННОСТИ ЗАДАЧИ
```

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```
 92 IV(J,I) = 2
    I = AA(4*NA + J + J - 1,I)
    IU(J) = I
    GOTO 65
100 IF(TAS - TE)101,91,91
101 SIJ = TE/TAS
    IF(SIJ - M(J))102,102,97
 97 IF(SS(J).EQ.1.0)SIJ = M(J)
    SS(J) = 0.0
    НАПРЯЖЕННОСТЬ SIJ ≤ 5
    IF(SIJ.GT.5.0)SIJ = 5.0
    СУММАРНАЯ НАПРЯЖЕННОСТЬ
102 SIJ1 = 1.0
    DO 113 J4 = 1,NA
    IF(J4 - J)103,113,103
103 TE1 = 0.0
    L1 = NP(J4)
    DO 112 I4 = 1,L1
    IF(IV(J4,I4))112,111,112
111 DX = TI(NA + J4 + J4 - 1,I4)
    IF(AA(J4,I4))112,112,110
110 TE1 = TE1 + DX
112 CONTINUE
    IF(T(J4) - (TE1 + TU(J4)))114,115,115
115 DX = 1.0
    GOTO 116
114 DX = TE1/(T(J4) - TU(J4))
116 IF(DX.LT.SIJ1)GOTO 113
    ВЫЧИСЛЕНО НАИБОЛЬШЕЕ ЗНАЧЕНИЕ SIJ1
    SIJ1 = DX
    MJ1 = M(J4)
113 CONTINUE
    ВЫЧИСЛЕНИЕ АДДИТИВНОГО СТРЕССА — AIJ
    AIJ = 0.0
    IF(SIJ1 - 1.0)120,120,121
121 IF(SIJ1 - MJ1)122,122,123
122 AIJ = (SIJ1 - 1.0)/(MJ1 - 1.0)
    GOTO 120
123 AIJ = 1.0
    ВЫЧИСЛЕНИЕ СПАЯННОСТИ — CIJ
120 CIJ = (SIJ*SIJ1 - 1.0)/(M(J)*MJ1 - 1.0)
    ВЫЧИСЛЕНИЕ СУММАРНОЙ НАПРЯЖЕННОСТИ — SSIJ
    ВЫБОР НАИБОЛЬШЕГО ЗНАЧЕНИЯ НАПРЯЖЕННОСТИ
    SSIJ = SIJ + AIJ
    SK(J) = SIJ
    IF(SIJ - SM(J))125,125,124
```

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```
124 NSM(J) = I
    SM(J) = SIJ
125 CK(J) = CIJ
    SCP(J) = SCP(J) + CIJ
    ЦИКЛИЧЕСКИЕ ПОДЗАДАЧИ
131 IF(AA(NA + J,I) — 5)140,130,140
130 PJ = TI(3*NA + J,I)
    I4 = TU(J)/PJ
    IF(I4*PJ.GT.TU(J))I4 = I4 — 1
    PJ = PJ*(I4 + 1)
    DX = PJ — TU(J)
    TAZ — ВРЕМЯ ОЖИДАНИЯ ПЕРИОДА ЦИКЛИЧЕСКОЙ ПОДЗА-
    ДАЧИ
    TAZ(J) = TAZ(J) + DX
    TU(J) = PJ
    ПОДЗАДАЧА ОБОРУДОВАНИЯ (ТИП E)
140 IF(AA(NA + J,I) — 3)1401,1402,1401
1402 TIJ = TI(NA + J + J — 1,I)
    TA(J) = TA(J) + TIJ
    GOTO 153
    ВЫЧИСЛЕНИЕ ВРЕМЕНИ ВЫПОЛНЕНИЯ ПОДЗАДАЧИ
1401 CALL НОРМА
    ВЫБОР НОРМАЛЬНО РАСПРЕДЕЛЕННОГО ЧИСЛА KIJ(ОБРАЩЕ-
    НИЕ)
    S1IJ = TI(NA + J + J,I)
    VIJ = T1IJ + KIJ*S1IJ
141 T1IJ = TI(NA + J + J — 1,I)
    IF(VIJ.LT.0.75*T1IJ)VIJ = T1IJ*0.75
    MJ = M(J)
    FJ = F(J)
    IF(SSIJ — MJ)142,150,150
142 DX = (SSIJ — 1.0)/(MJ — 1.0)
    DX = ((—1.829*DX + 3.472)*DX — 2.35)*DX + 1.0
    TIJ = FJ*VIJ*DX
    GOTO 153
150 IF(SSIJ — MJ — 1.0)151,151,152
151 TIJ = (2.0*(SSIJ + 0.5 — MJ)*VIJ — (SSIJ — MJ)*T1IJ)*FJ
    GOTO 153
152 TIJ = (3.0*VIJ — T1IJ)*FJ
153 IF((T(J) — TU(J))*(T(J) — TU(J) — TIJ))154,155,155
154 POS(J,IU(J)) = POS(J,IU(J)) + 1.0
155 TU(J) = TU(J) + TIJ
    BZP(J,I) = BZP(J,I) + TIJ
    SPH(J,I) = SPH(J,I) + SIJ
    SC(J,I) = SC(J,I) + CIJ
    IF(SIJ.GT.MJ)PH(J,I) = PH(J,I) + 1.0

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```
    IF(AA(NA + J,I) — 2)156,158,156
156 J4 = 0
    DO 157 J4 = 1,NA
    IF(J4 — J)159,157,159
159 TP(J4) = TP(J4) + TIJ
157 CONTINUE
    GOTO 149
158 TC(J) = TC(J) + TIJ
    ОПРЕДЕЛЕНИЕ УСПЕШНОСТИ ВЫПОЛНЕНИЯ ПОДЗАДАЧИ
149 CALL RAVNO
    ЭТО ОБРАЩЕНИЕ К ВЫЧИСЛЕНИЮ РАВНОМЕРНО РАСПР.
    ЧИСЛА R3
160 P1IJ = TI(4*NA + J,I)*BB(J)
    IF(SIJ — MJ)161,162,162
161 GI = ((MJ — 1.0)*R3 — SIJ + 1.0)/(MJ — SIJ)
    GOTO 170
162 IF(SIJ — MJ — 1.0)163,163,164
163 GI = (SIJ — MJ + R3)/(SIJ — MJ + 1.0)
    GOTO 170
164 GI = 0.5*(1.0 + R3)
170 FI = P1IJ — GI
    IF(FI)171,173,173
171 SN(J) = SN(J) + 1.0
    IV(J,I) = 1
    THE(J,I) = THE(J,I) + TIJ
    NHE(J,I) = NHE(J,I) + 1.0
    IF(SN(J) + SY(J) — 10.0)172,172,180
172 IX = AA(4*NA + J + J,I)
    IY = 0
    IU(J) = IX
    GOTO 200
173 SY(J) = SY(J) + 1.0
    IF(SN(J) + SY(J) — 10.0)174,174,180
174 IV(J,I) = 3
    IY = 1
    IX = AA(4*NA + J + J — 1,I)
    IU(J) = IX
    GOTO 200
    200 — ПЕРЕХОД К ЗАПИСИ ДАННЫХ ПО ОДНОЙ ПОДЗАДАЧЕ
    ОПРЕДЕЛЕНИЕ УРОВНЯ ПРИТЯЗАНИЙ
180 GIJ = TI(5*NA + J,I) + GK(J)
    BB(J) = 1.0
    I180 (J) = I180(J) + 1
    GK(J) = 0.0
    B = GIJ — SY(J)/(SY(J) + SN(J))
    ES(J) = ES(J) + B
```

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```
802 EMK(J) = B
    IF(B — EM(J))188,188,189
189 EM(J) = B
    NEM(J) = I
188 IF(B — EMI(J))800,801,801
800 EMI(J) = B
    NEMI(J) = I
    ЭТО ВЫБОР НАИБОЛЬШЕЙ И НАИМЕНЬШЕЙ РАЗНИЦЫ МЕЖДУ
    ЭФФЕКТИВНОСТЬЮ И УРОВНЕМ ПРИТЯЗАНИЙ
801 IF(B — 0.02)181,181,182
182 IF(SIJ — MJ)183,183,184
184 BB(J) = 1.0 — 0.08*B
    GOTO 185
183 BB(J) = 1.0 + 0.08*B
    GOTO 190
181 IF(B.GE. — 0.02)GOTO 190
    IF(SIJ — MJ)185,185,186
186 SS(J) = 1.0
    GOTO 190
185 CALL НОРМА
    ЭТО ОБРАЩЕНИЕ К НОРМАЛЬНОМУ ЗАКОНУ
    KIJ = 0.05 + 0.03*KIJ
    IF(KIJ.LT.0.01)KIJ = 0.01
    IF(B)410,190,400
400 GK(J) = GK(J) — KIJ
    GOTO 190
410 GK(J) = GK(J) + KIJ
190 IF(FI)172,174,174
    ПЕРЕХОД К ВЫБОРУ СЛЕДУЮЩЕГО ОПЕРАТОРА
    ЗАПИСЬ ДАННЫХ ПО ОДНОЙ ПОДЗАДАЧЕ ОДНОГО ОПЕРАТОРА
200 IF(ITI — 1)211,213,211
213 JZ = J
    IZ = I
    IVZ — ВАЖН. ПОДЗАДАЧИ, SZ — НАПРЯЖЕННОСТЬ,
    SSZ — СУММАРНАЯ НАПРЯЖЕННОСТЬ
    IVZ = AA(JZ,IZ)
    SZ = SIJ
    SSZ = SSIJ
    TOZ = TA(JZ)
    TBP = TIJ
    TOZ — ВРЕМЯ ОЖИДАНИЯ, TBP — ВРЕМЯ ВЫПОЛНЕНИЯ ПОД-
    ЗАДАЧИ,
    ITZ — ТИП ПОДЗАДАЧИ, TUZ — ВРЕМЯ ВЫП. ВСЕХ ПОСЛЕД.
    ПОДЗАДАЧ
    TUZ = TU(JZ)
    IY = 1 — УСПЕХ, 0 — НЕУДАЧА, CZ — СПАЯННОСТЬ
```

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```
      CZ = CIJ
      ITZ = AA(NA + JZ,IZ)
      IF(ITZ.LT.2)ITZ = 6
210   FORMAT(9H ОПЕРАТОР,I2,10H  ПОДЗАДАЧА,I3,6H  ТИПА,
     *A1,A6,9H ВР.ВЫП.=,F6.2,8H ВР.ОЖ.=,F6.2,9H ИСП.ВР.=,F6.2,
     *5H SIJ =,F4.2,6H SSIJ =,F4.2,5H CIJ =,F4.2,2X,A6)
212   WRITE(ПЧ1,210)JZ,IZ,MTZ(ITZ — 1),MTZ(IVZ + 5),
     *TBP,TOZ,TUZ,SZ,SSZ,CZ,MTZ(7 + IY)
211   GOTO 52
      ДАННЫЕ О ИТЕРАЦИИ — IT — НОМЕР ИТЕРАЦИИ, IYP —
      УКАЗАТ. РЕЗУЛЬТАТ.,
      TIB — ПОЛНОЕ ИСПОЛЬЗ. ВРЕМЕНИ, TPR — ВРЕМЯ ПЕРЕРАС-
      ХОДА
222   IYP = 0
      DO 220J = 1,NA
      IF(TU(J).GT.T(J))IYP = 1
220   CONTINUE
      ВЫЧИСЛЕНИЕ ПОЛНОГО ИСПОЛЬЗОВАННОГО ВРЕМЕНИ
      TIB = 0.0
      DO 221 J = 1,NA
      IF(TU(J).GT.TIB)TIB = TU(J)
221   CONTINUE
      TM = 1000000.0
      DO 250 J5 = 1,NA
      T5 = TU(J5)
      IF(T5 — TM)225,250,250
225   TM = T5
      JX = J5
250   CONTINUE
      TIB = TIB + TU(JX) — TC(JX)
      TIBS = TIBS + TIB
      ПЕРЕРАСХОД ВРЕМЕНИ
      DO 230 J = 1,NA
230   TPR(J) = TU(J) — T(J)
      ПРОИЗВОДИТЕЛЬНОСТЬ
      DO 231 J = 1,NA
231   PR(J) = SY(J)/(SY(J) + SN(J))
240   FORMAT(30X,10HИТЕРАЦИЯ,I4,12H ВЫПОЛНЕНА,2A5,
     *14H ПОЛНОЕ ВРЕМЯ,F8.2,4HСЕК.///128HXO M(J) F(J)
     *T(J)TU(J)TPR(J)TA(J)SM(J)SK(J)CK(J)TAZ(J)
     *EMK(J)EM(J)EM1(J)PR(J)TP(J))
241   FORMAT(I2,7F8.2,I2,5F8.2,I2,F8.2,I2,2F8.2)
      ВЫВОД РЕЗУЛЬТАТОВ ОДНОЙ ИТЕРАЦИИ, ЕСЛИ ITI = 2
      IF(ITI — 1)245,243,243
243   WRITE(ПЧ1,240)IT,IYC(IYP + IYP + 1),IYC(IYP + IYP + 2),TIB
      DO 244 J = 1,NA
```

[Continued, next page]

```
      WRITE(ПЧ1,241)J,M(J),F(J),T(J),TU(J),TPR(J),TA(J),SM(J),
     *NSM(J),SK(J),CK(J),TAZ(J),EMK(J),EM(J),NEM(J),EMI(J),
     *NEMI(J),PR(J),TP(J)
  244 CONTINUE
      КОЛИЧЕСТВО УСПЕШНЫХ ИТЕРАЦИЙ : NY
  245 IF(IYP.EQ.0)NY = NY + 1
      DO 251 J = 1,NA
      TSR(J) = TSR(J) + TU(J)
      TPRS(J) = TPRS(J) + TPR(J)
      TCS(J) = TCS(J) + TA(J)
      SMS(J) = SMS(J) + SM(J)
      SKS(J) = SKS(J) + SK(J)
      EMS(J) = EMS(J) + EM(J)
      EMKS(J) = EMK(J) + EMKS(J)
      EMIS(J) = EMIS(J) + EMI(J)
      PRS(J) = PRS(J) + PR(J)
      TAZS(J) = TAZS(J) + TAZ(J)
      NC(J) = NC(J) + SY(J) + SN(J)
      TPN(J) = TPN(J) + TP(J)
      SSY(J) = SSY(J) + SY(J)
      SSN(J) = SSN(J) + SN(J)
      IF(EM(J) - EMM(J))260,260,261
  261 EMM(J) = EM(J)
      NEMM(J) = NEM(J)
  260 IF(EMI(J) - EMIN(J))262,263,263
  262 EMIN(J) = EMI(J)
      NEMIN(J) = NEMI(J)
  263 IF(SMM(J) - SM(J))264,265,265
  264 SMM(J) = SM(J)
      NSMM(J) = NSM(J)
  265 CKS(J) = CKS(J) + CK(J)
  251 CONTINUE
      ЭТО ФОРМИРУЮТСЯ ДАННЫЕ ДЛЯ ПОЛУЧЕНИЯ СР.  ОЦЕНОК
      ПРОГОНА
      DO 270 J = 1,NA
      L1 = NP(J)
      DO 270 I = 1,L1
      СЧЕТ ЧИСЛА ПРОПУСКОВ ПОДЗАДАЧ
      IF(IV(J,I) - 2)272,271,272
  271 HP(J,I) = HP(J,I) + 1.0
  272 IF(IV(J,I) - 1)270,273,270
      СЧЕТ НЕВЫПОЛНЕННЫХ ПОДЗАДАЧ
  273 HE(J,I) = HE(J,I) + 1.0
  270 CONTINUE
      КОНЕЦ ИТЕРАЦИИ
      IF(IT - N)42,280,280
```

[Continued, next page]

```
    КОНЕЦ ПРОГОНА
280 DN = 1.0/N
    DO 281 J = 1,NA
    TSR(J) = TSR(J)*DN
    TPRS(J) = TPRS(J)*DN
    TCS(J) = TCS(J)*DN
    SMS(J) = SMS(J)*DN
    SKS(J) = SKS(J)*DN
    SCP(J) = SCP(J)/NC(J)
    PRS(J) = PRS(J)*DN
    TAZS(J) = TAZS(J)*DN
    TPNS(J) = TPN(J)*DN
    EMS(J) = EMS(J)*DN
    EMKS(J) = EMKS(J)*DN
    EMIS(J) = EMIS(J)*DN
    IF(I180(J))281,281,295
295 ES(J) = ES(J)/I180(J)
281 CKS(J) = CKS(J)*DN
    DO 290 J = 1,NA
    L1 = NP(J)
    APP(J) = 0.0
    DO 290 I = 1,L1
    APP(J) = APP(J) + HP(J,I)
290 CONTINUE
    NПРОГ = NПРОГ + 1
    TIWS = TIBS*DN
    ПЕЧАТЬ РЕЗУЛЬТАТОВ ЗА ОДИН ПРОГОН
    PRY = NY*100.0/N
    CALL PRINT
    GOTO 10
    END
```

Subroutine for Feeding Raw Modeling Data

```
    SUBROUTINE POINT
    INTEGER AA (24,50),NP(4)
    REAL T(4),TI(24,50),M(4),F(4),TK(9,50)
   *,ANG(9),TD(10,10)
    COMMON /D/TD,NG
    COMMON NAA,NTI,N,NA,NO,ITI,NP,NПРОГ,IMAX,
   *T,M,F/K/TI,AA,PR1,PR2,PR3,PR4,PR5
    CALL СПЕЦ(ЗАКР,ВК1,ПЧ1)
    CALL СПЕЦ(ОТЫ,В,ПЧ1)
  5 FORMAT(//60H ---------------------------------
   *------------------------//)
```

[Continued, next page]

```
 6 FORMAT(4F18.0)
 7 FORMAT(/41X,36HКОЭФФИЦИЕНТЫ ДИСКРИМИНАНТНЫХ
   ФУНКЦИЙ/)
 8 FORMAT(5F20.5)
10 FORMAT(3X,6I3,2F8.0)
11 FORMAT(//49H СТАТИСТИЧЕСКИЙ ПРОГНОЗ ОПЕРАТОРСКОЙ
  •ДЕЯТЕЛЬНОСТИ//)
12 FORMAT(3X,12I3)
14 FORMAT(3X,12F6.0)
16 FORMAT(3X,2F6.0)
18 FORMAT(9E8.5)
20 FORMAT(3A4,2A1,3F4.2,9F6.0)
21 FORMAT(/30H ДАННЫЕ СРЕДНЕГО ОПЕРАТОРА: M=,F4.2,3H
   F =,F4.2)
22 FORMAT(//11X,24HИСХОДНЫЕ ДАННЫЕ ИМИТАЦИИ//
  •36H ЗАДАННОЕ ЧИСЛО ИТЕРАЦИЙ............,I6/
  •36H КОД ПЕЧАТИ РЕЗУЛЬТАТОВ.............,I6//
  •9H ОПЕРАТОР,4X,10HКОЛИЧЕСТВО,4X,17HНОРМАТИВНОЕ
  •ВРЕМЯ/4X,1HN,9X,8HПОДЗАДАЧ,11,X,6HРАБОТЫ)
23 FORMAT(/43X,32HКОЭФФИЦИЕНТЫ УРАВНЕНИЙ РЕГРЕССИИ/)
24 FORMAT(I5,9X,I5,6X,F11.3,5H СЕК.)
25 FORMAT(9E13.5)
26 FORMAT(//20X,8HОПЕРАТОР,I3//4X,9HПОДЗАДАЧА,
  •5X,35H РАНЕЕ ВЫП. ОПЕРАТО —
  •18X,9HПОДЗАДАЧА,8H,3X,13H—СЛЕДУЮЩАЯ ПОДЗАДАЧА В СЛУ-
   ЧАЕ/
  •3H N, 14HСУЩЕСТ. ТИП,6X,1HN,7X,3HРОМ,4X,
  •15HУСПЕХА НЕУДАЧИ)
28 FORMAT(I3,I6,I7,I8,I9,2I8)
29 FORMAT(//11H ИСПЫТУЕМЫЙ,2X,3A4,1X,A1,1H.,A1,1H.,3X,
  •22HПРЕОБРАЗОВАННЫЕ ДАННЫЕ)
30 FORMAT(//16X,18HПАРАМЕТРЫ ПОДЗАДАЧ)
32 FORMAT(//6H НОМЕР,3X,6HРАННИЙ,8H МАТЕМ.,3X,
  •14HСТАНД. ПЕРИОД,2X,12HВЕРОЯТ— УРО—/
  •54H ПОДЗА— МОМЕНТ ОЖИДАН. ОТКЛО—. ЦИКЛ.
  •НОСТЬ ВЕНЬ/55HДАЧИ НАЧАЛА ВРЕМЕНИ
  •НЕНИЕ. ПОДЗ. УСПЕХА ПРИТ.)
34 FORMAT(I4,F11.3,F9.3,4F8.3)
35 FORMAT(//11H ИСПЫТУЕМЫЙ,2X,3A4,1X,A1,1H.A1,1H.,2X,
  •2HM-,F4.2,4H F =,F4.2,4HG =,F4.2,1X/19H ПОКАЗАТЕЛИ ТЕСТОВ:,
  •/5X,2H1),E13.5,4H 2),E13.5,4H 3),E13.5/
  •5X,2H4),E13.5,4H 5),E13.5,4H 6),E13.5/
  •5X,2H7),E13.5,4H 8),E13.5)
   IF(NПРОГ)100,40,100
40 CALL СПЕЦ(ОТВ,ПОДЗА,BK1)
   READ(BK1,10)N,NA,NO,IT1,(NP(J),J = 1,NA),(T(J),J = 1,NA)
```

[Continued, next page]

```
      IMAX = 1
      ОПРЕДЕЛЕНИЕ НАИБОЛЬШЕГО ЧИСЛА ПОДЗАДАЧ
      DO 44 J = 1,NA
      IZI = NP(J)
      IF(IZI — IMAX)44,42,42
   42 IMAX = IZI
   44 CONTINUE
      NAA = 6*NA
      NTI = 6*NA
      READ(BK1,12)((AA(J,I),J = 1,NAA),I = 1,IMAX)
      CALL СПЕЦ(ЗАВ,ПОДЗА,BK1)
    2 CALL СПЕЦ(ОТВ,ПАРАМ,BK1)
      READ(BK1,14)((TI(J,I),J = 1,NAA),I = 1,IMAX)
      CALL СПЕЦ(ЗАВ,ПАРАМ,BK1)
      ОПРЕДЕЛЕНИЕ НОМЕРА СРЕДНЕГО ОПЕРАТОРА
      И ВВОД ЕГО ДАННЫХ
    3 CALL СПЕЦ(ОТВ,ОПЕР1,BK1)
      DO 50 J = 1,NA
      IF(NO — J)45,50,45
   45 READ(BK1,16)M(J),F(J)
   50 CONTINUE
      CALL СПЕЦ(ЗАВ,ОПЕР1,BK1)
      ВВОД МАТРИЦЫ КОЭФФИЦИЕНТОВ УРАВНЕНИЙ РЕГРЕССИИ
    4 CALL СПЕЦ(ОТВ,КОЭФФ,BK1)
      L = NP(NO)
      READ(BK1,18)((TK(J,I),J = 1,9) I =1,L)
      CALL СПЕЦ(ЗАВ,КОЭФФ,BK1)
      NG = 3
      NK = 10
      ВВОД МАТРИЦЫ КОЭФФИЦИЕНТОВ ДИСКРИМИНАНТНЫХ
      ФУНКЦИЙ
    9 CALL СПЕЦ(ОТВ,ДИСКР,BK1)
      DO 51 I = 1,NG
      READ(BK1,6)(TD(J,I),J = 1,NK)
   51 CONTINUE
      CALL СПЕЦ(ЗАВ,ДИСКР,BK1)
      ЗАПИСЬ ВВЕДЕННЫХ ДАННЫХ
      WRITE(ПЧ1,22)N,NA,NO,ITI
      DO 52 J = 1,NA
      WRITE(ПЧ1,24)J,NP(J),T(J)
   52 CONTINUE
      DO 60 J = 1,NA
      MJ = NP(J)
      WRITE(ПЧ1,26)J
      DO 54 I = 1,MJ
      WRITE(ПЧ1,28)I,AA(J,I),AA(NA + J,I),AA(2*NA + 2*J — 1,I),
```

[Continued, next page]

```
   *AA(2*NA + 2*J,I),AA(4*NA + 2*J - 1,I),AA(4*NA + 2*J,I)
54 CONTINUE
   WRITE(ПЧ1,30)
   WRITE(ПЧ1,32)
   DO 56 I = 1,MJ
   WRITE(ПЧ1,34)I,TI(J,I),TI(NA + J + J - 1,I),TI(NA + J + J,I),
   *TI(3*NA + J,I),TI(4*NA + J,I),TI(5*NA + J,I)
56 CONTINUE
60 CONTINUE
   DO 64 J = 1,NA
   IF(NO - J)62,64,62
62 WRITE(ПЧ1,21)M(J),F(J)
64 CONTINUE
   WRITE(ПЧ1,23)
   WRITE(ПЧ1,25)((TK(J,I),J = 1,9),I = 1,L)
   WRITE(ПЧ1,7)
   WRITE(ПЧ1,8)((TD(J,I),J = 1,10),I = 1,NG)
100 CALL СПЕЦ(ОТВ,ТЕСТЫ,ВК1)
   READ(ВК1,20)PR1,PR2,PR3,PR4,PR5,M(NO),F(NO),GR
   *,(ANG(I),I = 1,9)
   CALL СПЕЦ(ЗАВ,ТЕСТЫ,ВК1)
   IF(ANG(9).EQ.111111.0)GOTO 40
   IF(ANG(9).EQ.222222.0)GOTO 2
   IF(ANG)(9).EQ333333.0)GOTO 3
   ПРЕОБРАЗОВАНИЕ ВВЕДЕННЫХ РАНЕЕ ПАРАМЕТРОВ
   ПОДЗАДАЧ
   С УЧЕТОМ ИНДИВИДУАЛЬНЫХ СВОЙСТВ
   ИСПЫТУЕМОГО ОПЕРАТОРА
   WRITE(ПЧ1,5)
   WRITE(ПЧ1,11)
   WRITE(ПЧ1,35)PR1,PR2,PR3,PR4,PR5,M(NO),F(NO),GR,
   *(ANG(I),I = 1,8)
   K = 9
   DO 110 I = 1,L
   BB = TK(K,I)
   DO 105 J = 1,8
   BB = BB + TK(J,I)*ANG(J)
105 CONTINUE
   IF(BB.LT.0.2)BB = 0.2
   TI(NA + NO + NO - 1,I) = BB
   TI(5*NA + NO,I) = GR
110 CONTINUE
   ЗАПИСЬ ПРЕОБРАЗОВАННОЙ МАТРИЦЫ ДАННЫХ
   IF(ANG(9).NE.555555.0)GOTO 120
   WRITE(ПЧ1,29)PR1,PR2,PR3,PR4,PR5
   WRITE(ПЧ1,32)
   DO 120 I = 1,L
   WRITE(ПЧ1,34)I,TI(NO,I),TI(NA + NO + NO - 1,I),TI(NA + NO
   + NO,I),
   TI(3*NA + NO,I),TI(4*NA + NO,I),TI(5*NA + NO,I)
120 CONTINUE
   RETURN
   END
```

Subroutine for Feeding the Results of Simulation Modeling

```
      SUBROUTINE PRINT
      INTEGER AA(24,50),NP(4)
     *,NEMIN(4),NEMM(4),NSMM(4)
      REAL T(4),TI(24,50),M(4),F(4),TD(10,10),SSY(4),
     *SSN(4),APP(4),PRS(4),TSR(4),TCS(4),TPNS(4),TAZS(4),
     *TPRS(4),SMM(4),SMS(4),SKS(4),EMIN(4),
     *EMM(4),ES(4),EMS(4),EMIS(4),SCP(4),CKS(4),CI(10),
     *XBAR(10),NC(4)
      COMMON NAA,NTI,N,NA,NO,ITI,NP,NПРОГ,IMAX,
     *T,M,F/K/TI,AA,PR1,PR2,PR3,PR4,PR5
      COMMON /Q/NY,PRY,TIBS,NC,SSY,SSN,APP,PRS,
     *TSR,TCS,TPNS,TAZS,TPRS
      COMMON /B/SMM,NSMM,SMS,SKS,EMIN,NEMIN,EMM,
     *NEMM,
     *ES,EMS,EMIS,SCP,CKS /
      COMMON /D/TD,NG
      CALL СПЕЦ(ЗАКР,ВК1,ПЧ1)
      CALL СПЕЦ(ОТЫ,С,ПЧ1)
   10 FORMAT(//12X,10HРЕЗУЛЬТАТЫ,I3,8H ПРОГОНА//
     *20H КОЛИЧЕСТВО ИТЕРАЦИЙ, 7X,I5/25H ИЗ НИХ ВЫПОЛНЕНО
     *УСПЕШНО,I6/26H ПРОЦЕНТ УСПЕШНЫХ ИТЕРАЦИЙ,F9.3/
     *25H СРЕДНЕЕ ВРЕМЯ ВЫПОЛНЕНИЯ/6X,9HАЛГОРИТМА,11X,
     *F9.3,5H СЕК.)
   20 FORMAT(//12X,27HРЕЗУЛЬТАТЫ РАБОТЫ ОПЕРАТОРА//
     *36H ОБЩЕЕ ЧИСЛО ВЫПОЛНЕННЫХ ПОДЗАДАЧ....,F10.2/
     *36H ИЗ НИХ — ВЫПОЛНЕНО УСПЕШНО...,F10.2/
     *36H — ВЫПОЛНЕНО НЕУДАЧНО...,F10.2/
     *36H ОБЩЕЕ ЧИСЛО ПРОПУЩЕННЫХ ПОДЗАДАЧ...,F10.2/
     *36H СРЕДНЯЯ ПРОИЗВОДИТЕЛЬНОСТЬ.........,F15.7//
     *36H СРЕДНЕЕ ВРЕМЯ РАБОТЫ...............,F11.3,5H СЕК./
     *36H СРЕДНЕЕ ВРЕМЯ ОЖИДАНИЯ............,F11.3,5H СЕК./
     *36H СРЕДНЕЕ ВРЕМЯ ПРОСТОЯ..............,F11.3,5H СЕК./
     *23H СРЕДНЕЕ ВРЕМЯ ОЖИДАНИЯ/
     *36H В ЦИКЛИЧЕСКИХ ПОДЗАДАЧАХ...........,F11.3,5H СЕК./
     *36H СРЕДНИЙ ПЕРЕРАСХОД ВРЕМЕНИ.........,F11.3,5H СЕК.)
   30 FORMAT(//39H МАКСИМАЛЬНАЯ НАПРЯЖЕННОСТЬ............,F8.3/
     *24H (ВОЗНИКЛА В ПОДЗАДАЧЕ N,I3,1H)/
     *39H СРЕДНЕЕ МАКСИМАЛЬНЫХ НАПРЯЖЕННОСТЕЙ...,F8.3/
     *39H СРЕДНЕЕ КОНЕЧНЫХ НАПРЯЖЕННОСТЕЙ.......,F8.3/)
   40 FORMAT(/51H РАЗНОСТЬ МЕЖДУ ЭФФЕКТИВНОСТЬЮ И
      УРОВНЕМ
     *ПРИТЯЗАНИЙ//30H — МИНИМАЛЬНАЯ...........,F9.5,
     *11H (ПОДЗАДАЧА,I3,1H)/30H — МАКСИМАЛЬНАЯ.........,
     *F9.5,11H (ПОДЗАДАЧА,I3,1H)/30H — СРЕДНЕЕ ЗНАЧЕНИЕ...,
     *F9.5/30H — СРЕДНЕЕ ЗНАЧЕНИЕ МАКСИМУМОВ.,F9.5/
     *30H — СРЕДНЕЕ КОНЕЧНОЕ ЗНАЧЕНИЕ...,F9.5//
     *40H СРЕДНЯЯ СПАЯННОСТЬ ЗА ПРОГОН.........,F9.5/
     *40H СРЕДНЯЯ СПАЯННОСТЬ В КОНЦЕ ИТЕРАЦИИ.....F9.5/)
```

[Continued, next page]

```
50 FORMAT(16X,16H****************/
  *38H ВЫВОД: ПО РЕЗУЛЬТАТАМ ПРОГНОЗИРОВАНИЯ/
  *8X,10HИСПЫТУЕМЫЙ,4X,3A4,1X,A1,1H.,A1,1H./
  *8X,20HМОЖЕТ БЫТЬ ОТНЕСЕН К,I3,7H ГРУППЕ/
  *8X,25HОПЕРАТОРОВ С ВЕРОЯТНОСТЬЮ,F8.5///)
   J = NO
   CI(1) = NC(J)
   CI(2) = SSY(J)
   CI(3) = SSN(J)
   CI(4) = APP(J)
   CI(5) = PRS(J)
   CI(6) = TSR(J)
   CI(7) = SMS(J)
   CI(8) = ES(J)
   CI(9) = SCP(J)
   K = 10
   DO 60 I = 1,NG
   BB = TD(K,I)
   DO 55 L = 1,9
55 BB = BB + TD(L,I)*CI(L)
60 XBAR(I) = BB
   L1 = 1
   BB = XBAR(1)
   DO 70 K = 2,NG
   IF(BB - XBAR(K))65,70,70
65 L1 = K
   BB = XBAR(K)
70 CONTINUE
   PL = 0.0
   DO 80 K = 1,NG
80 PL = PL + EXP(XBAR(K) - BB)
   P = 1.0/PL
   WRITE(ПЧ1,10)NПРОГ,N,NY,PRY,TIBS
   WRITE(ПЧ1,20)NC(J),SSY(J),SSN(J),APP(J),PRS(J),TSR(J),
  *TCS(J),TPNS(J),TAZS(J),TPRS(J)
   WRITE(ПЧ1,30)SMM(J),NSMM(J),SMS(J),SKS(J)
   WRITE(ПЧ1,40)EMIN(J),NEMIN(J),EMM(J),NEMM(J),ES(J),
  *EMS(J),EMIS(J),SCP(J),CKS(J)
   WRITE(ПЧ1,50)PR1,PR2,PR3,PR4,PR5,L1,P
   RETURN
   END
```

Appendix 2. Program of the Simulation Information Model of Operator Group Activity

```
1   REM МОДЕЛЬ ГРУППОВОЙ ВЗАИМОСВЯЗАННОЙ ДЕЯТЕЛЬ-
    НОСТИ
10  DIM R[5],K[5],M[5],P[5],N[5],G[5]
20  DIM C[5],W[5],L[5],I[5],Y[5],U[5],A[5]
24  READ K[1],K[2],K[3],K[4],K[5]
27  LET M = 3
28  LET I = 5
29  READ R[1],R[2],R[3],R[4],R[5]
32  READ G[1],G[2],G[3],G[4],G[5]
36  READ M[1],M[2],M[3],M[4],M[5]
40  READ P[1],P[2],P[3],P[4],P[5]
42  LET N1 = 0
44  LET N1 = N1 + 1
46  PRINT «ПРОГОН»;N1
48  PRINT «H,T,N,C1»;
50  INPUT H,T,N,C1
55  LET HO = H
60  MAT I = ZER
63  MAT A = ZER
65  MAT Y = ZER
70  LET C5 = C3 = Q = E = Z = 0
80  LET L = SO = Z1 = C2 = E1 = T1 = 0
90  MAT C = ZER
92  MAT N = ZER
93  MAT U = ZER
94  MAT W = ZER
95  LET TO = T
96  MAT L = ZER
100 LET F1 = F = H/T
110 FOR X = 1 TO M
120 LET B[X] = 1/M
```

[Continued, next page]

```
128 LET F[X] = F1/M
130 NEXT X
140 LET F[1] = B[1]*F1
150 LET FO = F[1]
160 FOR X = 2 TO M
170 LET F[X] = B[X]*F1
180 IF F[X] > FO THEN 200
190 LET FO = F[X]
200 NEXT X
300 LET T9 = 1/FO
310 IF 2*T9 > TO THEN 1300
320 FOR X = 1 TO M
330 LET T[X] = 1/F[X]
340 LET S[X] = R[X]/T[X]
342 IF S[X] > 1 THEN 350
344 LET S[X] = 1
350 IF S[X] < M[X] THEN 380
360 LET D[X] = 2
370 GOTO 430
380 LET O[X] = (S[X] - 1)/(M[X] - 1)
385 LET N6 = O[X]
390 LET D[X] = K[1] + K[2]*O[X]
400 FOR J = 3 TO I
405 LET N6 = N6*O[X]
410 LET D[X] = D[X] + K[J]*N6
420 NEXT J
430 LET V[X] = T9/T[X]
440 LET C[X] = C[X] + V[X] - 1
450 IF C[X] < 1 THEN 480
460 LET V[X] = V[X] + C[X]
470 LET C[X] = C[X] - INT(C[X])
480 LET V[X] = INT(V[X])
530 NEXT X
540 LET R1 = 0
550 FOR X = 1 TO M
560 LET L = L + V[X]
570 LET L[X] = L[X] + V[X]
575 LET N5 = V[X]
580 FOR Y = 1 TO N5
590 LET RO = 0
600 FOR Z9 = 1 TO 48
610 LET RO = RO + RND(O)
620 NEXT Z9
630 LET RO = G[X]*RO/2 + (R[X] - 12*G[X])
640 LET RO = RO*D[X]
650 IF RO > T[X] THEN 670
```

[Continued, next page]

```
660 IF (P[X] — RND(O)) > 0 THEN 690
670 LET N[X] = N[X] + 1
680 GOTO 710
690 LET W[X] = W[X] + 1
700 LET S0 = S0 + 1
710 NEXT Y
712 IF W[X] # 0 THEN 720
714 LET C5 = C5 + 1
720 LET R1 = R1 + W[X]/L[X]
730 NEXT X
750 LET ZO = 1
760 FOR X = 1 TO M
762 IF C5 = 0 THEN 770
764 LET B[X] = 1/M
765 IF R1 = 0 THEN 790
766 GOTO 780
767 IF W[X] = 0 THEN 790
770 LET B[X] = (W[X]/L[X])/R1
780 LET ZO = ZO*B[X]
785 LET U[X] = U[X] + S[X]
790 NEXT X
795 LET C5 = 0
800 LET Z0 = Z0*(M — M)
810 LET Z1 = Z1 + Z0
820 LET C2 = C2 + 1
830 LET EO = F/F1
840 LET E1 = E1 + E0
850 LET Q1 = SO/L
880 LET T1 = T1 + T9
890 LET TO = T — T1
900 LET HO = H — S0
910 IF TO < = 0 THEN 940
920 LET F1 = HO/TO
930 GOTO 140
940 LET Z1 = Z1/C2
950 LET E1 = E1/C2
960 FOR X = 1 TO M
970 LET Q[X] = W[X]/L[X]
975 LET E[X] = (F/M)/F[X]
978 LET U[X] = U[X]/C2
980 NEXT X
990 IF C1 = 0 THEN 1060
998 PRINT «КАЧЕСТВО», «ЭФФЕКТ.», «НАПРЯЖ.», «ПРЕД», «ОБРАБ.»
1000 FOR X = 1 TO M
1005 PRINT Q[X],E[X],U[X],L[X],W[X]
1006 NEXT X
```

[Continued, next page]

```
1010 PRINT «Z1 =»; Z1;«E1 =»;E1;«Q1 =»;Q1
1040 PRINT «H =»;H;«T =»;T;«HO =»;HO
1050 PRINT
1060 LET Z = Z + Z1
1070 LET E = E + E1
1080 LET Q = Q + Q1
1090 FOR X = 1 TO M
1100 LET I[X] = I[X] + Q[X]
1105 LET Y[X] = Y[X] + E[X]
1108 LET A[X] = A[X] + U[X]
1110 NEXT X
1120 LET C3 = C3 + 1
1130 IF C3 = N THEN 1150
1140 GOTO 80
1150 PFINT «ЗА»;N;«ИТЕРАЦИЙ»
1153 PRINT «ОПЕР.»,«НАДЕЖН.»,«КАЧЕСТВО»,«ЭФФЕКТ.»,
     «НАПРЯЖ.»
1155 FOR X = 1 TO M
1160 PRINT X,P[X],I[X]/C3,Y[X]/C3,A[X]/C3
1165 NEXT X
1170 PRINT «Z =»;Z/C3;«E =»;E/C3;«Q =»;Q/C3
1200 PRINT
1220 PRINT «КОД РАБОТЫ»;
1230 INPUT N2
1240 IF N2 = 1 THEN 38
1280 GOTO 44
1300 LET T9 = TO
1310 LET V[1] = INT(T9*F[1] +.5)
1315 LET V1 = V[1]
1320 FOR X = 2 TO M — 1
1330 IF F[X — 1] > B[X — 1]*V[X — 1]/TO THEN 1360
1340 LET V[X] = INT(T9*F[X])
1350 GOTO 1370
1360 LET V[X] = INT(T9*F[X] +.5)
1370 LET V1 = V1 + V[X]
1380 NEXT X
1390 LET V[M] = HO — V1
1400 GOTO 540
1500 DATA 1,—2.35,3.472,—1.829,0
1550 DATA .4,.4,.4,0,0
1600 DATA .1,.1,.1,0,0
1650 DATA 2,2,2,0,0
1700 DATA .9,.9,.7,0,0
4000 END
READY
```

Appendix 3. Symbols of Variables in Information Simulation Model of Group Activity

H -- number of presentable information symbols
T -- time of work
M -- number of operators in group
R[x] -- matrix of average times of information processing
G[x] -- matrix of mean quadratic deviations of information processing time
K[J] -- matrix of coefficients of stress polynomial
M[x] -- matrix of stress thresholds
P[x] -- matrix of probabilities of success
C1 -- print code for one iteration
T[x] -- matrix of times in which each operator processes one information symbol
F[x] -- matrix of intensities of information flows
V[x] -- number of information symbols in cycle
C[x] -- matrix of supplementary information symbols
S[x] -- matrix of stresses
A[x] -- matric of independent variables (arguments) of polynomial
D[x] -- matrix of coefficients of time deformation
L -- number of information symbols presented
L[x] -- matrix of information symbols presented to each operator
W[x] -- matrix of successfully processed information symbols
N[x] -- matrix of erroneously processed information symbols
B[x] -- matrix of coefficients of information loading of channels
R0 -- time of processing an information symbol
Z0 -- product of coefficients of information loading
Z1 -- current value of operator teamwork
C2 -- cycle counter
E0 -- efficiency of work of group in cycle
E1 -- current value of work efficiency
T1 -- time used
T9 -- time of last cycle
T0 -- remaining time
S0 -- total number of successfully processed informacion symbols
H0 -- remaining number of information symbols
E[x] -- matrix of values of work efficiency of operators in cycle
Q[x] -- matrix of values of quality of operator activity in cycle
C6 -- number of stress-related failures
C3 -- iteration counter
J[x] -- matrix of values of quality of operators' work in n iterations
Y[x] -- matrix of values of efficiency of operators' work in n iterations

BIBLIOGRAPHY

To Chapters 1 and 2

1. K. Marx, "Kapital," in K. Marx and F. Engels, "Sochineniya" [Works], 2nd Ed, Vol 23, Book 1, pp 80-93.

2. K. Marx, ibid, p 361.

3. V. I. Lenin, "The Scientific System of Squeezing out Sweat," "Poln. Sobr. Soch." [Complete Works], Vol 23, pp 18-19.

4. V. I. Lenin, "The Taylor System -- Enslavement of the Human Being by the Machine," ibid, Vol 24, pp 369-371.

5. K. K. Platonov, "Voprosy Psikhologii Truda" [Issues of Labor Psychology], Moscow, "Meditsina," 1970, 219 pages.

6. R. B. Cattel, "Personality and Motivation Structure and Measurement," New York: Yonkers-on-Hudson, 1957, 948 pages.

7. F. B. Berezin, M. P. Miroshnikov, and R. F. Rozhanets, "Metodika Mnogostoronnego Issledovaniya Lichnosti" [Methodology for Multifaceted Study of the Personality], Moscow, "Meditsina," 1976, 176 pages.

8. J. A. Taylor, "A Personality Scale of Manifest Anxiety," J. ABNORMAL AND SOC. PSYCHOL., 1953, 48, No 2, pp 285-290.

9. Ye. A. Mileryan (editor), "Psikhologicheskiy Otbor Letchikov" [Psychological Selection of Pilots], Kiev, 1966, 234 pages.

10. A. V. Il'in, "The Rhythm of the Psyche and the Labor Process," in "Na Psikhologicheskom Fronte" [On the Psychological Front], 1931, Vol 2, pp 60-61.

11. K. K. Platonov, "Psikhologiya Letnego Truda" [The Psychology of Flight Work], Moscow, "Voyenizdat," 1960, 351 pages.

12. F. Taylor, "Scientific Organization of Labor," 3rd ed, Moscow, "Izd-vo i tip. 1-ya im. Vorovskogo Transpechati," 1924, 292 pages (translation from English).

13. F. Taylor, "Scientific Foundations of the Organization of Industrial Enterprises," Moscow, "Levenstern," 1916, 114 pages (translation from English).

14. I. M. Sechenov, "Uchastiye Nervnoy Sistemy v Rabochikh Dvizheniyakh Cheloveka -- Izbr. Proizvedeniya" [Participation of the Nervous System in Human Work Motions -- Selected Works], Moscow, "Izd-vo AN SSSR," 1952, Vol 1, pp 510-517.

15. I. M. Sechenov, "Ocherk Rabochikh Dvizheniy Cheloveka -- Izbr. Tr." [Essay on Human Work Motions -- Selected Works], Moscow, "Vzesoyuz. In-t Eksperim. Meditsiny," 1935, 139 pages.

16. O. Lipman, "Vybor Professiy" [Choice of Occupations], Prague, 1923, 32 pages.

17. M. I. Bobneva, "Psychological Design as the New Goal and Facet of Human Factors Engineering," in "18 Mezhdunar. Psikhol. Kongr.: Tez. Soobshch." [The 18th

International Psychological Congress: Abstracts of Communications], Moscow, 1966, Vol 2, pp 452-453.

18. V. P. Zinchenko, A. N. Leont'yev, and D. Yu. Panov, "Problems of Human Factors Engineering," in "Inzhernaya Psikhologiya" [Human Factors Engineering], Moscow, "Izd-vo Mosk. Un-ta," 1964, pp 5-23.

19. A. N. Leont'yev, and B. F. Lomov, "People and Machines," VOPR. PSIKHOLOGII, 1963, No 5, pp 29-37.

20. K. K. Platonov (editor), "Lichnost' i Trud" [The Individual Personality and Labor], Moscow, "Mysl'," 1965, 365 pages.

21. D. Yu. Panov, and D. A. Oshanin, "The Human Being in Automatic Control Systems," in "Kibernetiku na Sluzhbu Kommunizmu" [Cybernetics in the Service of Communism], Moscow, "Gosenergoizdat," 1961, pp 173-184.

22. M. I. Bobneva, "Tekhnicheskaya Psikhologiya" [Industrial Psychology], Moscow, "Nauka," 1966, 127 pages.

23. G. M. Zarakovskiy, G. M., "Psikhofiziologicheskiy Analiz Trudovoy Deyatel'nosti" [Psychophysiological Analysis of Labor Activity], Moscow, "Nauka," 1966, 114 pages.

24. O. A. Konopkin, "The Speed of Information Receiving by a Person and Conscious, Deliberate Regulation of Human Activity," in "Sistemy Chelovek i Avtomat" [The Man and Automaton System], Moscow, "Nauka," 1965, pp 119-127.

25. B. F. Lomov, V. M. Nikolayev, and V. F. Rubakhin, "Timely Theoretical Problems of Human Factors Engineering," in "Materialy 3 Vsesoyuz. S"yezda O-va Psikhologov SSSR" [Materials of the 3rd All-Union Congress of the Society of Psychologists of the USSR], Moscow, 1968, Vol 3, Vyp 1, pp 57-58.

26. V. N. Pushkin, "Operativnoye Myshleniye v Bol'shikh Sistemakh" [Operational Thinking in Large Systems], Moscow-Leningrad, "Energiya," 1965, 375 pages.

27. V. N. Pushkin, "Some Fundamental Issues of Psychology and Cybernetics," VOPR. PSIKHOLOGII, 1967, No 1, pp 168-171.

28. M. I. Vinogradov, "Fiziologiya Trudovykh Protsessov" [The Physiology of Labor Processes], Moscow, "Meditsina," 1966, 367 pages.

29. S. A. Kosilov, "Ocherki Fiziologii Truda" [Essays on Labor Physiology], Moscow, "Meditsina," 1965, 379 pages.

30. Z. M. Zolina, "Fiziologicheskiye Osnovy Ratsional'noy Organizatsii Truda na Konveyyere" [The Physiological Foundations of Rational Organization of Labor on the Conveyor Line], Moscow, "Meditsina," 1967, 176 pages.

31. A. I. Kikolov, "Umstvenno-Emotsional'noye Napryazheniye za Pul'tom Upravleniya" [Mental-Emotional Stress at the Control Console], Moscow, "Meditsina," 1967, 176 pages.

32. K. K. Platonov, "Psychological Foundations of Scientific Organization of Labor," in "Psikhologicheskiye i Esteticheskiye Osnovy NOT" [Psychological and Aesthetic Foundations of Scientific Organization of Labor], Moscow, 1967, pp 35-54.

33. "Issues of Production Organization in the United States: Report of the Brigade of English Specialists on Issues of Production Organization in the United States," Moscow, "Izd-vo Inostr. Lit.," 1965, 230 pages (translation from English).

34. V. V. Rozenblat, "Definitions of Certain General Concepts of Ergonomics and Labor Physiology Related to Characterizing the Functional Stress of the Organism During Labor Activity," in "Materialy Vseros. Mezhvuz. Konf. po Nauch. Org. Truda i Upr. Pr-vom. Sektsiya 'Ergon. Vopr. Org. Truda'" [Materials of the All-Russian Interschool Conference on Scientific Organization of Labor and Production Control. The Section "Ergonomic Issues of Labor Organization], Sverdlovsk, 1970, pp 3-6.

35. V. G. Zhukov, and P. I. Ignat'yev, "Fiziologo-Gigiyenicheskiye Voprosy NOT" [Physiological-Hygienic Issues of Scientific Organization of Labor], Sverdlovsk, "Sverdl. In-t Nar. Khoz-va," 1972, 62 pages.

36. V. P. Solov'yeva, "Mental and Nervous-Emotional Stress in Different Types of Labor Activity," abstract of dissertation for the degree doctor of medical sciences, Moscow, 1972, 31 pages.

37. K. M. Gurevich, "Professional'naya Prigodnost' i Osnovnyye Svoystva Nervnoy Sistemy" [Occupational Suitability and the Basic Characteristics of the Nervous System], Moscow, "Nauka," 1970, 272 pages.

38. A. I. Prokhorov, A. A. Ramyalis, and M. V. Freydina, "Monitoring State as a Technique for Evaluating the Effect of Various Factors on the Efficiency of Operator Activity," in "Kontrol' Sostoyaniya Cheloveka-Operatora" [Monitoring the State of the Human Operator], Moscow-Vilnius, 1971, pp 13-21.

39. A. I. Samoylova, "Experiment with Comprehensive Study of Working Conditions and the State of Health of Female Workers in a Scientific Organization of Labor System," in "Materialy Vseros."... op. cit., fn 34, pp 18-22.

40. V. A. Adamovich-Gerasimov, D. I. Vasil'yeva, V. N. Margolin, and V. A. Plamkin, "Development of Rational Regimes of Labor and Rest under Conditions of a Five-Day Work Week," ibid, pp 61-64.

41. N. D. Levitov, "Psikhologiya Truda" [Labor Psychology], Moscow, "Uchpedgiz," 1963, 340 pages.

42. M. A. Gendin, and R. A. Gisova, "Professiograms as a Constituent Part of Scientific Organization of the Labor of Workers," ibid., pp 85-87.

43. Ye. A. Klimov, "Individual'nyy Stil' Deyatel'nosti v Zavisimosti ot Tipologicheskikh Svoystv Nervnoy Sistemy" [The Individual Style of Activity Dependent on Typological Characteristics of the Nervous System], Kazan', "Izd-vo Kaz. Un-ta," 1969, 273 pages.

44. V. V. Mochalin, "Evaluation of the Psychophysiological Criteria of Vocational Selection by Means of a Newly Developed Set of Instruments (Using the Example of the Occupation of Railway Engineer," author's abstract of a disseration for the degree of candidate of biological sciences, Moscow, 1964, 32 pages.

45. L. N. Zafirov, G. A. Aminev, V. I. Volodin, and S. V. Sudnitsyn, "Study of Working Conditions and the Physiological State of Rotary Conveyor Workers," in "Materialy Vseros. Mezhvuz. Konf." ... op. cit., fn 34, pp 40-43.

46. I. M. Sechenov, "On the Question of the Effect of Stimulation of the Sense Nerves on a Person's Muscular Work," in "Izb. Tr." [Selected Works], Moscow, "Vsesoyuz. In-t Eksperim. Meditsiny," 1935, pp 151-163.

47. F. R. Dunayevskiy, "Problema Professional'nogo Otbora (Vybor Professiy)" [The Problem of Vocational Selection (Choice of Occupations)], Khar'kov, "Izd-vo In-ta Truda i Zhurn. 'Put' Prosveshcheniya,'" 1923, 68 pages.

48. A. K. Gastev, "Ustanovka Proizvodstva Metodom TsITa" [Setting up Production by the Central Institute of Labor Method], Moscow-Leningrad, "Gosizdat," 1927, 148 pages.

49. V. S. Merlin, "The Psychological Foundations for Teaching Self-Control," SOV. PEDAGOGIKA, 1939, No 11/12, pp 138-148.

50. G. Z. Bednyy, and F. A. Voskoboynikov, "The Issue of the Adaptability of the Individual to the Objective Requirements of an Activity," in "Psikhofiziologicheskiye Osnovy Professional'nogo Otbora: Tez. 1 Vsesoyuz. Simpoz." [The Psychophysiological Foundations of Vocational Selection: Abstracts of the 1st All-Union Symposium], Kiev, 1973, pp 9-10.

51. A. A. Bagrov, M. P. Yegorov, and O. V. Goncharova, "Medical-Physiological Selection in Planned Professional Advancement of Personnel at the Volga Automotive Plant," in ibid., pp 7-8.

52. O. N. Luk'yanova, T. A. Berezanets, T. M. Semik, L. I. Shumilina, and Yu. R. Varenik, "Experiment with Creating Operational Stress under Lab Conditions," in "Neyrobionika i Problemy Bioelektricheskogo Upravleniya" [Neurobionics and Problems of Bioelectric Control], Kiev, 1975, pp 18-28.

53. A. Binet, "Introduction to Experimental Psychology," St. Petersburg, "Tip. V. Bezobrazova," 1903, 215 pages (translation from French).

54. Br. Simon, "The English School and Intelligence Tests," Moscow, "Izd-vo APN RSFSR," 1958, 252 pages (translation from English).

55. V. N. Shubkin, "Sotsiologicheskiye Opyty" [Sociological Experiments], Moscow, "Mysl'," 1970, 288 pages.

56. G. I. Andreyeva (editor), "Lektsiya po Metodike Konkretnykh Sotsial'nykh Issledovaniy" [Lecture on the Methodology of Concrete Social Research], Moscow, "Izd-vo Mosk. Un-ta," 1972, 202 pages.

57. T. I. Tepenitsina, "Investigating Attention by the Correction Test Method During the Process of Expert Evaluation of Work Capability," VOPR. PSIKHOLOGII, 1959, No 5, pp 145-153.

58. V. M. Bleykher, "Klinicheskaya Patopsikhologiya" [Clinical Pathopsychology], Tashkent, "Meditsina UzSSR," 1976, 325 pages.

59. A. N. Leont'yev, and Yu. B. Gippenreyter (editors), "Praktikum po Psikhologii" [Practical Course in Psychology], Moscow, "Izd-vo Mosk. Un-ta," 1972, 247 pages.

60. F. I. Grishko, "Methodology for Determining the Speed of Information Processing (by Means of Tables)," GIGIYENA I SANITARIYA, 1974, No 3, p 68.

61. A. O. Navakitkyan, and V. V. Kryzhanovskaya, "Determining the Speed of Information Processing by Means of Tables," FIZIOL. ZHURN., 1970, No 10, p 697.

62. G. K. Sereda (editor), "Inzhenernaya Psikhologiya" [Human Factors Engineering], Kiev, "Vishcha shkola," 1976, 308 pages.

63. H. J. Eysenck, "Test Your Abilities," Moscow, "Mir," 1972, 176 pages.

64. K. M. Gurevich, and I. V. Ravich-Shcherbo, "What Should Be the 'Criterion of Intelligence?'" LIT. GAZ., 1975, No 5, p 13.

65. V. S. Deryabin, "Chuvstva, Vlecheniya, Emotsii" [Feelings, Inclinations, and Emotions], Leningrad, "Nauka," 1974, 258 pages.

66. A. Ye. Ol'shannikova, V. V. Semenov, and L. M. Smirnov, "Evaluation of Methodologies for Diagnosing Emotionality," VOPR. PSIKHOLOGII, 1976, No 5, pp 103-113.

67. A. Ye. Ol'shannikova, "The Sign of Dominant Emotions and Background EEG's in Adolescents," NOVYYE ISSLED. V PSIKHOLOGII, 1974, No 1, pp 60-62.

68. S. V. Korzh, "Quantitative Evaluation of Strength of Will," VOPR. PSIKHOLOGII, 1976, No 1, pp 118-121.

69. Ye. S. Makhlakh, and I. A. Rapoport, "The Question of Measuring Efforts of Will and the Volitional Qualities of an Individual," VOPR. PSIKHOLOGII, 1976, No 2, pp 133-137.

70. I. P. Pavlov, "Physiological Doctrine of the Types of Nervous Systems and Temperaments," in "Poln. Sobr. Soch." [Complete Works], 2nd Ed, Moscow-Leningrad, "Izd-vo AN SSSR," 1952, Vol 3, pp 77-78.

71. V. D. Nebylitsyn, "Osnovnyye Svoystva Nervnoy Sistemy Cheloveka" [Basic Characteristics of the Human Nervous System], Moscow, "Prosveshcheniye," 1966, 381 pages.

72. V. D. Nebylitsyn, "Psikhofiziologicheskiye Issledovaniya Individual'nykh Razlichiy" [The Psychophysiological Investigation of Individual Differences], Moscow, "Nauka," 1976, 336 pages.

73. V. D. Nebylitsyn, "Timely Problems of Differential Psychology," VOPR. PSIKHOLOGII, 1971, No 6, pp 13-26.

74. H. J. Eysenck, "The Structure of Human Personality," London, Methuen, 1948, 448 pages.

75. J. A. Taylor, "The Relationship of Anxiety to Conditioned Eyesid Response," J. EXP. PSYCHOL., 1952, 41, pp 81-92.

76. P. B. Zil'berman, "The Emotional Stability of the Operator," author's abstract of dissertation for the degree of candidate of psychological sciences, Kiev, 1969, 21 pages.

77. V. L. Marishchuk, "The Question of the Emotional Stability of Flight Cadets and Possibilities of Improving It Using Physical Training Equipment," author's abstract of dissertation for the degree of candidate of psychological sciences, Leningrad, 1969, 25 pages.

78. L. M. Abolin, "The Relationship of Psychological and Physiological Correlates of Emotional Stability (Based on Findings from a Study of Soccer Players of Different Ages and Skill Groups)," author's abstract of dissertation for the degree of candidate of psychological sciences, Moscow, 1974, 25 pages.

79. G. Kh. Shingarov, "Emotsii i Chuvstva kak Forma Otrazheniya Deyatel'nosti" [Emotions and Feelings as a Form of Reflection of Activity], Moscow, "Nauka," 1971, 223 pages.

80. P. Press, "Emotions," in "Voprosy Motivatsii i Emotsiy" [Questions of Motivation and Emotions], Moscow, 1973, pp 131-189.

81. P. V. Simonov, "Teoriya Otrazheniya i Psikhofiziologiya Emotsiy" [Theory of Reflection and the Psychophysiology of Emotions], Moscow, "Nauka," 1970, 141 pages.

82. N. I. Nayenko, and O. V. Ovchinnikova, "Distinguishing the State of Emotional Tension," PSIKHOL. ISSLED., 1970, Vyp 2, p 5.

83. F. Grodins, "Teoriya Regulirovaniya i Biologicheskiye Sistemy" [Theory of Regulation and Biological Systems], Moscow, "Mir," 1966, 254 pages.

84. P. V. Bundzen, N. N. Vasileyevskiy, A. M. Zingerman, D. N. Menitskiy, N. B. Suvorov, V. V. Trubachev, A. V. Chubarov, and B. M. Mishkin, "Ocherki Prikladnoy Neyrokibernetiki" [Essays on Applied Neurocybernetics], Leningrad, "Meditsina," 1973, 232 pages.

85. A. M. Zingerman, V. D. Volkova, D. N. Menitskiy, P. V. Bundzen, and B. M. Mishkin, "Typological Characteristics of Adaption That Determine the Effectiveness of Labor Activity," FIZIOL. ZHURN. SSSR, 1974, 9, No 10, pp 1481-1493.

86. L. D. Yermolayeva-Tomina, "Individual Differences in the Skin Glavanic Reaction," in B. M. Teplov (editor), "Tipologicheskiye Osobennosti Vysshey Nervnoy Deyatel'nosti Cheloveka" [Typological Characteristics of Human Higher Nervous Activity], Moscow, "Prosveshcheniye, 1965, Vol 4, pp 212-238.

87. L. D. Yermolayeva-Tomina, "Evaluation of Indicators of the Dynamism of the Nervous System by the Skin Galvanic Method," PROBL. DIFFERENTS. PSIKHOLOGII, 1969, 6, pp 214-227.

88. Z. G. Turovskaya, Ye. L. Berezhkovskaya, and Z. M. Aleksandrovskaya, "The Individual Style of Work and Psychophysiological Characteristics of Operators in Chemical Production," VOPR. PSIKHOLOGII, 1972, No 5, pp 77-78.

89. B. M. Teplov, "Current State of the Issue of Types of Human Higher Nervous Activity and Methodology for Defining Them," in "7 Mezhdunar. Kong. Antropolog. i Etnogr. Nauk." [7th International Congress of Anthropological and Ethnographic Sciences], Moscow, "Nauka," 1964, pp 1-15.

90. Z. G. Turovskaya, "The Relationship of Certain Indicators of the Strength and Mobility of the Human Nervous System," in "Tipologicheskiye Osobennosti Vysshey Nervnoy Deyatel'nosti Cheloveka" [Typological Characteristics of Human Higher Nervous Activity], edited by B. M. Teplov, Moscow, "Izd-vo APN RSFSR," 1963, Vol 3, pp 248-261.

91. L. B. Yermolayeva-Tomina, "Some Characteristics of Attention Related to the Strength of the Nervous System," DOKL. AKAD. PED. NAUK, 1957, No 3, pp 97-100.

92. L. B. Yermolayeva-Tomina, "Concentration of Attention and the Strength of the Nervous System," in "Tipologicheskiye Osobennosti"... op. cit., fn 90, Vol 2, pp 92-106.

93. V. D. Nebylitsyn, "Reaction Time and the Strength of the Nervous System," DOKL.APN RSFSR, 1960, No 4, pp 93-100.

94. A. Ye. Ol'shannikova, and N. I. Aleksandrova, "The Reliability of Indicators of the Motor Reaction," PROBL. DIFFERENTS. PSIKHFIZIOLOGII, 1969, 6, pp 253-265.

95. O. A. Sirotin, "Some Psychophysiological Correlates of the Emotional Stability of Athletes," NOVYYE ISSLED. V PSIKHOLOGII, 1974, No 1, pp 62-65.

96. E. A. Golubeva, "Studying the Bioelectric Correlates of Memory in Differential Psychology," VOPR. PSIKHOLOGII, 1972, No 1, pp 25-36.

97. E. A. Golubeva, "The Reactions of Reorganizing the Biocurrents of the Brain and Psychological Characteristics of the Nervous System," in "Tipologicheskiye Osobennosti"... op. cit., fn 86, pp 111-129.

98. V. I. Rozhdestvenskaya, E. A. Golubeva, and L. B. Yermolayeva-Tomina, "General and Partial Factors in Strength of the Nervous System," PROBL. DIFFERENTS. PSIKHOFIZIOLOGII, 1969, 6, pp 15-37.

99. V. I. Rozhdestvenskaya, and I. A. Levochkina, "The Functional State During Monotonous Work and Strength of the Nervous System," PROBL. DIFFERENTS. PSIKHOLOFIZIOLOGII, 1972, 7, pp 194-223.

100. V. S. Klyagin, "Band Analysis of the EEG and the Strength of the Nervous System," NOVYYE ISSLED. PSIKHOLOGII, 1974, No 1, pp 53-55.

101. T. F. Bazylevich, and N. A. Leonova, "The Manifestation of Strength as a General Characteristic of the Nervous System in Set Circumstances," NOVYYE ISSLED. V PSIKHOLOGII, 1974, No 1, pp 51-52.

102. V. S. Merlin, and E. I. Mastvilisker, "New Techniques of Investigating the Strength of the Stimulation Process," VOPR. PSIKHOLOGII, 1971, No 6, pp 151-155.

103. L. A. Kopytova, "The Individual Style of Labor Activity of Mechanics Depending on Strength of the Nervous System in Relation to Stimulation," VOPR. PSIKHOLOGII, 1964, No 1, pp 25-34.

104. S. A. Solov'yeva, "Individual Psychological Differences in the Impact of Motives and Nervous-Mental Stress on Memorization," PROBL. EXPERIM. PSIKHOLOGII LICHNOSTI, 1968, Vyp 5, pp 23-26.

105. N. S. Utkina, "Typological Differences in the Influence of the Pedagogical Evaluation on Certain Characteristics of Attention ," in "Tipologicheskiye Issledovaniya po Psikhologii Truda" [Typological Studies in Labor Psychology], Perm', 1964, pp 113-151.

106. V. I. Rozhdestvenskaya, "Manifestation of Strength of the Nervous System in the Ability of Nerve Cells to Endure Prolonged, Concentrated Stimulation," in "Tipologicheskiye Osobennosti"... op. cit., fn 90, 1959, Vol 2, pp 39-48.

107. V. I. Rozhdestvenskaya, "Experiment with Determining the Strength of the Process of Stimulation by Characteristics of Its Irradiation and Concentration in the Visual Analyzer," VOPR. PSIKHOLOGII, 1955, No 3, pp 90-99.

108. P. G. Saprykin, and Ye. A. Mileryan, "Experiment with Development of a Methodology for Experimental Study of Individual Characteristics of Human Higher Nervous Activity,' in "Dokl. na. Soveshch. po. Vopr. Psikhologii" [Reports at the Conference on Issues of Psychology], Moscow, 1954, pp 31-35.

109. V. I. Rozhdestvenskaya, "Determining the Strength of the Inhibition Process in a Human Being in Experiments Involving Prolonging the Action of a Differentiating Stimulus," in "Tipologicheskiye Osobennosti"... op. cit., fn 90, Vol 3, 1963, pp 108-117.

110. Ye. F. Melikhova, "Correlation Analysis of the Results of Separate Tests for the Strength, Balance, and Mobility of Nervous Processes in Dogs," ZHURN. VYSSH. NERV. DEYATEL'NOSTI, 1964, 14, Vyp 5, pp 808-813.

111. V. I. Rozhdestvenskaya, "The Manifestation of Typological Characteristics of the Human Nervous System in Producing Delayed Photochemical Reflexes," in "Tipologicheskiye Osobennosti"... op. cit., fn 90, 1963, Vol 3, pp 117-133.

112. K. M. Gurevich, "Investigation of Positive and Inhibitory Stimuli in the Motor Reaction," in ibid., pp 240-248.

113. N. S. Leytis, "The Question of Typological Differences Following Stimulation and Inhibition Processes," in "Tipological Osobennosti"... op. cit., fn 90, 1956, Vol 1, pp 182-307.

114. Z. G. Turovskaya, "The Nature of Typological Differences in the Manifestation of the Aftereffect of Nerve Processes," VOPR. PSIKHOLOGII, 1963, No 3, pp 33-47.

115. Z. G. Turovskaya, "The Relationship of Certain Indicators of the Strength and Mobility of the Human Nervous System," in "Tipologicheskiye Osobennosti"..., op. cit., fn 90, Vol 3, pp 248-262.

116. N. I. Chuprikova, "The Question of the Dynamics of Nerve Stimulation in the Interaction of Visual and Motor Reactions," IZV. APN RSFSR, 1954, No 53, p 291.

117. N. I. Chuprikova, "Local Summation of Positive and Inhibitory Pulses from the Old Signaling System in Direct Cortical Projections," in "Pogranichnyye Problemy Psikhologii i Fiziologii" [Boundary Problems of Psychology and Physiology], Moscow, "Izd-vo APN RSFSR," 1961, pp 52-63.

118. M. S. Kolesnikov, "Slabyy Tip Vysshey Nervnoy Deyatel'nosti Zhivotnykh" [The Weak Type of Higher Nervous Activity in Animals], Minsk, "Izd-vo AN BSSR," 1963, 168 pages.

119. V. K. Fedorov, "Study of the Mobility of Nerve Processes in Mice," FIZIOL. ZHURN. SSSR, 1951, 37, No 2, pp 145-151.

120. P. D. Kharchenko, "Zapazdyvayushchiye Uslovnyye Refleksy" [Delaying Conditioned Reflexes], Kiev, "Izd-vo Kiev. Un-ta," 1960, 302 pages.

121. B. M. Teplov, "New Findings on Study of the Properties of the Human Nervous System,' in "Tipologicheskiye Osobennosti"... op. cit., fn 90, Vol 3, pp 3-47.

122. I. V. Revich-Shcherbo, and L. A. Shvarts, "Relationship of the Speed of Occurence and Speed of Cessation of Nerve Processes as Indicators of the Mobility of Nerve Processes," VOPR. PSIKHOLOGII, 1959, No 5, pp 97-104.

123. L. A. Shvarts, "Speed of Recovery of Absolute Sensitivity After Exposure to Light as an Indicator of the Mobility (Lability) of Nerve Processes and Other Tests for Mobility," in "Tipologicheskiye Osobennosti"... op. cit., fn 90, Vol 3, pp 232-240.

124. Z. A. Golubeva, and L. A. Shvarts, "Relationship of Bioelectric Indicators of Lability with Critical Rate of Blinking and the Speed of Recovery of Light Sensitivity," in "Tipologicheskiye Osobennosti"... op. cit., fn 90, Vol 3, pp 130-140.

125. R. S. Mnukhina, "The Mechanisms of Interdependence of the Cerebellum and the Cortex of the Large Hemispheres in Light of the Vvedenskiy-Ukhtomskiy Theory," FIZIOL. ZHURN. SSSR, 1952, 38, No 3, pp 288-297.

126. N. N. Zislina, "Electrophysiological Investigation of the Functional Mobility of the Child's Brain by the Technique of Rhythmic Light Stimuli," ZHURN. VYSSH. NERV. DEYATEL'NOSTI, 1955, 5, Vyp 5, pp 677-685.

127. A. G. Kopylov, "Evaluation of the Functional State of the Human Cerebral Cortex by the Technique of Electroencephalographic Curves of Assimilation of a Rhythm," in "Voprosy Teorii i Praktiki Elektroentsefalografii" [Questions of the Theory and Practice of Electroencephalography], Leningrad, "Izd-vo Leningr. Un-ta," 1956, pp 96-108.

128. S. A. Izyumova, "Characteristics of the Assymetry in the Length of the Ascending and Descending Phases of the EEG at Rest as a Possible Indicator of Stable Individual Differences," NOVYYE ISSLED. PSIKHOLOGII, 1974, No 1, pp 55-57.

129. V. V. Gorbunov, "Study of the Human EEG with Different Typological Characteristics of Higher Nervous Activity for Purposes of Vocational Selection," in "Psikhologicheskiye Osnovy Professional'nogo Otbora: Tez. 1 Vsesoyuz. Simpoz." [Psychological Foundations of Vocational Selection: Abstracts from the First All-Union Symposium], Kiev, "Nauk. Dumka," 1973, pp 28-29.

130. M. K. Akimova, "Formation of a Speed Habit in Relation to Individual Characteristics of Strength and Lability of Nerve Processes," VOPR. PSIKHOLOGII, 1972, No 2, pp 60-65.

131. V. T. Kozlova, "The Manifestation of the Lability-Inertia of Nerve Processes in Thinking and Speech Activity," in "Psikhofiziologicheskiye Voprosy Stanovleniya Professionala" [Psychophysiological Questions of the Formation of a Professional], Moscow, "Sov. Rossiya," 1974, pp 141-157.

132. N. V. Makarenko, V. V. Sirotskiy, and V. A. Troshikhin, "Methodology for Evaluating the Primary Characteristics of Human Nerve Activity," in "Neyrobionika i Problemy Bioelektricheskogo Upravleniya" [Neurobionics and Problems of Bioelectric Control], Kiev, "IK AN USSR," 1975, pp 41-49.

133. Ye. A. Rushkevich, and I. D. Golova, "Atlas dlya Issledovaniya Vysshey Nervnoy Deyatel'nosti Cheloveka pri Nekotorykh Logicheskikh Operatsiyakh" [Atlas for Investigation of Higher Nervous Activity of Human Beings in Certain Logical Operations], Kiev, "Naukova Dumka," 1975, 271 pages.

134. E. A. Golubeva, "Attempt at an Investigation of the Reaction of Reorganization of Biocurrents of the Brain as an Indicator of Individual Differences Related to Equilibrium of Nerve Processes," in "Tipologicheskiye Osobennosti"... op. cit., fn. 90, Vol 3, pp 164-180.

135. V. K. Krasuskiy, "Methodology for Evaluating the Characteristics of Nerve Processes in Dogs, Used by the Laboratory of the Physiology and Genetics of Types of Higher Nervous Activity," ZHURN. VYSSH. NERV. DEYATEL'NOSTI, 1963, 13, Vyp 1, pp 165-176.

136. E. P. Kokorina, "Methodology for Evaluating the Characteristics of Primary Nerve Processes in Defining the Type of Higher Nervous Activity of Animals by the Technique of Motor Food Conditioned Reflexes," ZHURN. VYSSH. NERV. DEYATEL'NOSTI, 1963, 13, Vyp 2, pp 361-370.

137. I. O. Mayyer, "Osnovnyye Svoystva Nervnykh Protsessov u Detey Doshkol'nogo Vosrasta" [Primary Characteristics of Nerve Processes in Preschool Children], Tbilisi, "Sabchota Sakartvelo," 1963, 175 pages.

138. V. M. Bleykher, and L. F. Burlachuk, "Psikhologicheskaya Diagnostika Intellekta i Lichnosti" [Psychological Diagnosis of Intelligence and Personality], Kiev, "Vishcha Shkola," 1978, 142 pages.

139. L. D. Gissen, "Study of Certain Characteristics of the Personality of Athletes of Composite National Teams," in "Materialy Itog. Nauch. Sessii In-ta za 1968 g." [Materials of the Final Scientific Session of the Institute for 1968], Moscow, "Vsesoyuz. NII Fiz. Kul'tury," 1970, p 1.

140. D. A. Grey, "Strength of the Nervous System. Introvertism-Extrovertism, Conditioned Reflexes, and the Reaction of Activity," VOPR. PSIKHOLOGII, 1968, No 3, pp 40-46.

141. L. D. Gissen, "Psikhologiya i Psikhogigiyena v Sporte" [Psychology and Psychological Hygiene in Sports], Moscow, "Fizkul'tura i Sport," 1973, 150 pages.

142. N. V. Imedadze, "Anxiety as a Factor in Preschool Learning," in "Psikhologicheskiye Issledovaniya" [Psychological Research], Tbilisi, "Metsniyereba," 1966, pp 49-58.

143. T. A. Nemchina, "Study of the State of Anxiety in Neurotics Using the Questionnaire Technique," in "Voprosy Sovremennoy Nevrologii" [Issues of Contemporary Neurology], Leningrad, 1966, pp 51-54.

144. V. E. Mil'man, "Some Methods of Studying Individual Psychological Differences That Affect Behavior in a Stress Situation," VOPR. PSIKHOLOGII, 1968, No 2, pp 160-168.

145. G. L. Mangan, and C. J. Adrak, "EEG-Correlates of Perceptual Vigilance and Defense, " PERCEPT. MOTOR SKILLS, 1962, 14, pp 197-198.

146. G. K. Nelson, "The Measurement and Significance of Brain Rhythms," FRANC. S. AFRIC. INST. ELECTR. ENGRS, 1960, 51, pp 2-10.

147. M. A. B. Brazier, J. E. Finesinger, and S. A. Cobb, "A Contract Between Electroencephalograms of 100 Psychoneurotic Patients and Those of 500 Normal Adults," AMER. J. PSYCHIAT., 1945, 101, pp 443-448.

148. H. Gastaut, G. Gastaut, A. Roger, J. Corriol, and R. Naguet, "Etude Electroencephalographique du Cycle d'extitabilite Cortical," EEG. CLIN. PEUROPHYSIOL., 1951, 3, pp 401-406.

149. L. J. Saul, H. Davis, and P. A. Davis, "Psychological Correlations [of] the Electroencephalogram," EEG, CLIN. NEUROPHYSIOL., 1949, 1, pp 551-557.

150. H. Gastaut, "The Brain Stem and Cerebral Electrogenesis in Relation to Consciousness," in "Brain Mechanisms and Consciousness," Oxford, Blackwell Sci. Publ., 1956, pp 249-283.

151. B. N. Yakovets, "The Readiness of the Human Operator for Emergency Action Related to Attitude Toward the Job," author's abstract of dissertation for the degree of candidate of psychological sciences, Tartu, "Izd-vo Tart. Un-ta," 1971, 19 pages.

152. K. K. Platonov, and L. M. Shvarts, "Ocherki Psikhologii dlya Letchikov" [Essays on Psychology for Pilots], Moscow-Leningrad, 1948, 192 pages.

153. S. M. Oya, "Characteristics of Pre-Competition Changes and Emotional Stability in Representatives of Various Sports," in "Psykhologicheskiye Voprosy Trenirovki i Gotovnosti Sportsmenov k Sorevnovaniyam" [Psychological Questions of Training and the Readiness of Athletes for Competition], Moscow, "Fizkul'tura i Sport," 1969, pp 21-24.

154. O. V. Dashkevich, "Emotions in Sport and Their Regulation," author's abstract of dissertation for the degree of candidate of medical sciences, Moscow, 1970, 23 pages.

155. P. B. Zil'berman, "Emotional Stability and Stress," in "Materialy Vsesoyuz. Simpoz. 'Psikhol. Stress v Sporte'" [Materials of the All-Union Symposium on Psychological Stress in Sports], Perm', 1973, pp 14-17.

156. K. M. Gurevich, and V. V. Matveyev, "The Suitability of Operators and Ways of Determining It," in "Voprosy Professional'noy Prigodnosti Operatorskogo Personala Energosistem" [Questions of the Professional Suitability of Operator Personnel in the Power Systems], Moscow, "Prosveshcheniye," 1966, pp 9-13.

157. K. A. Ivanov-Muromskiy, and O. N. Luk'yanova, "Human Beings in the State of Operational Stress," FIZIOLOGIYA CHELOVEKA, 1975, No 3, pp 459-468.

158. V. F. Matveyev, "Psychological Manifestation of the Primary Characteristics of the Nervous System in Power System Operators under Emergency Conditions," in "Tipologicheskiye Osobennosti Vysshey Nervnoy Deyatel' Deyatel'nosti Cheloveka" [Typological Characteristics of Human Higher Nervous Activity], Moscow, "Prosveshcheniye," 1965, Vol 4, pp 34-60.

159. S. M. Oya, "Possibility of Regulating the Pre-Competition State on the Basis of Objectively Measured Data," in "Psikhologicheskiye Voprosy Sportivnoy Trenirovki" [Psychological Issues of Sports Training], Moscow, "Fizkul'tura i Sport," 1967, pp 28-31.

160. A. V. Rodinov, "Investigation of the State of Athletes with Different Characteristics of Nervous Systems at the Start of Competition," in ibid., pp 17-23.

161. Z. G. Turovskaya, "Characteristics of Change in the Electroencephalogram during Stress and Its Aftereffect," VOPR. PSIKHOLOGII, 1970, No 1, pp 53-62.

162. R. Wherry, "Model for the Study of Psychological Stress," AEROSPACE MED., 1966, 37, pp 495-500.

163. V. V. Gnezditskiy, "Quantitative Evaluation of Reactive Changes in the EEG -- Normal and with Focal Impairment of the Cerebral Cortex (Use of the

Technique of Automatic Regulation)," author's abstract of dissertation for the degree of candidate of biological sciences, Moscow, 1974, 27 pages.

164. A. M. Zimkina, A. M. Zingerman, T. D. Dokutov, and B. M. Shishkin, "The Functional State of the Central Nervous System as a Factor That Defines Work Potential," in "12 S"yezd Vsesoyuz. Fiziol. O-va" [12th Congress of the All-Union Society of Physiology], Leningrad, "Nauka," 1975, Vol 1, pp 285-286 (abstracts of reports, Tibilisi, 1975).

165. D. A. Oshanin, and O. A. Konopkin (editors), "Psykhologicheskiye Voprosy Regulyatsii Deyatel'nosti" [Psychological Questions of Regulating Activity], Moscow, "Pedagogika," 1973, 207 pages.

166. M. Kotik, "Samoregulyatsiya i Nadezhnost' Cheloveka-Operatora" [Self-Regulation and the Reliability of the Human Operator], Tallinn, "Valgus," 1974, 166 pages.

167. A. M. Zingerman, and B. M. Shishkin, "The Issue of Individual Differences in Self-Regulation of Physiological Functions," FIZIOLOGIYA CHELOVEKA, 1977, 3, No 1, pp 124-135.

To Chapter 3, Section 1

1. P. Patkai, "The Secretion of Catecholamines and Activity," in "Emotsional'nyy Stress" [Emotional Stress], Leningrad, "Meditsina," 1970, pp 63-66.

2. M. Frankenkhoyzer, "Some Aspects of Research in Physiological Psychology," in ibid., pp 24-36.

3. V. D. Nebylitsyn, "Osnovnyye Svoystva Nervnoy Sistemy Cheloveka" [Primary Characteristics of the Human Nervous System], Moscow, "Prosveshcheniye," 1966, 381 pages.

4. M. Rogovin, "Mental Stress and Mental Disorders," ZHURN. NEVROPATOLOGII I PSIKHIATRII, 1962, 62, Vyp 11, pp 1731-1740.

5. H. Selye, "The Stress of Life," New York, McGraw-Hill, 1956, 200 pages.

6. E. Gel'gorn, and Dzh. Lufborrou, "Emotsii i Emotsional'nyye Rasstroystva" Emotions and Emotional Disorders], Moscow, "Mir," 1966, 672 pages.

7. K. Bernar, "Lektsiya po Eksperimental'noy Patologii" [Lecture on Experimental Pathology], Moscow-Leningrad, "Meditsina," 1937, 512 pages.

8. W. B. Cannon, "The Wisdom of the Body," New York, W. W. Norton Co. Inc., 1932, 333 pages.

9. L. D. Orbeli, "Lektsiya po Fiziologii Nervnoy Sistemy" [Lecture on the Physiology of the Nervous System], Moscow-Leningrad, "Medgiz," 1938, 312 pages.

10. P. V. Zdrodovskiy, "Adaptive-Protective Mechanisms of the Organism," VESTN. AMN SSSR, 1960, Vyp 5, pp 657-661.

11. V. M. Morozov, "The Theory of Stress in Psychiatry," ZHURN. NEVROPATOLOGII I PSIKHIATRII, 1957, 57, Vyp 5, pp 657-661.

12. Ya. Ya. Gordon, "Some Theories Current in Western Medicine," MED. ZHURN. UZBEKISTANA, 1960, No 4, pp 5-11.

13. H. Selye, "Na Urovne Tselogo Organizma" [On the Level of the Whole Organism], Moscow, "Nauka," 1972, 122 pages.

14. H. Selye,"Nonspecific Resistance," PATOL. FIZIOLOGIYA I EKSPERIM. TERAPIYA, 1961, 5, No 4, pp 3-15.

15. Ibid.

16. H. Selye, "Ocherki ob Adaptatsionnom Sindrome" [Essays on the Adaptation Syndrome], Moscow, "Nauka," 1960, 254 pages.

17. I. T. Kurtsin, "Psychogenic Stress and Its Physiological Mechanisms," in "Materialy 17 Nauch. Konf. Fiziologov Yuga RSFSR" [Materials of the 17th Scientific Conference of Physiologists of the Southern RSFSR], Stavropol', 1969, Vol 1, pp 34-35.

18. I. I. Finkel', "Indicators of Reactivity in the Morphology of the General Adaptation Syndrome," PROBL. ENDOKRINOLOGII I GORMONOTERAPII, 1963, 2, No 1, pp 82-89.

19. O. K. Khmel'nitskiy, and Yu. A. Medvedev, "Pathological Aspects of the General Adaptation Syndrome," ARKH. PATOLOGII, 1972, 33, Vyp 12, pp 62-72.

20. L. L. Lengli, "Hormonal Synergism in Reactions to Stress," FIZIOL. ZHURN. SSSR, 1958, 44, No 2, p 153.

21. A. A. Shteyn, "Selye's Conception (Stress, the General Adaptation Syndrome, and Adaptation Sickness)," VESTN. DERMATOLOGII, 1961, No 12, pp 22-29.

22. V. T. Bakhur, "Emotional Stress and Neuroses," VOYENNO-MED. ZHURN., 1971, No 9, pp 24-28.

23. G. I. Kositskiy, and V. M. Smirnov, "Nervnaya Sistema i Stress" [The Nervous System and Stress], Moscow,"Nauka," 1970, 200 pages.

24. V. M. Morozov, "Hans Selye: History of the Adaptation Syndrome," ZHURN. NEVROPATOLOGII I PSIKHIATRII, 1955, 55, Vyp 3, pp 223-230.

25. M. M. Reydler, "Stress. Excessive Tension of the Organism. Causes. Ways to Avoid It," PRIRODA, 1965, No 5, pp 51-56.

26. D. S. Futer, "Clinical Remarks of a Clinical Doctor on Selye's Theory of the Adaptative Syndrome," ZHURN NEVROPATOLOGII I PSIKHIATRII, 1962, 62, Vyp 80, pp 1253-1261.

27. G. I. Tsaregorodtsev, and S. A. Chesnokova, "Filosofskiye Problemy Meditsiny" [Philosophical Problems of Medicine], Moscow, "Znaniye," 1962, 48 pages.

28. A. D. Speranskiy, "Elementy Postroyeniya Teorii Meditsiny" [Elements of the Structure of the Theory of Medicine], Moscow-Leningrad, "Izd-vo Vsesoyuz. In-ta Eksperim. Meditsiny" 1935, 344 pages.

29. F. G. Agarkov, "The Role of the Nerve Components of Regulation in the Mechanism of Development of Specifically and Nonspecifically Heightened Organism Resistance to Unfavorable Heat Influences," in "Materialy Konf. po Probl. Adaptatsii, Trenirovki i Dr. Sposobam Povysheniya Ustoychivosti Organizma" [Materials from the Conference on Problems of Adaptation, Training, and Other Ways of Increasing Organism Stability], Vinnitsa, 1962, pp 12-13.

30. P. K. Anokhin, "General Principles of Formation of the Organism's Protective Functions," in "16 Sessiya Obshch. Sobr. AMN SSSR: Tez. Nauch. Dokl." [The 16th Session of the General Meeting of the USSR Academy of Medical Sciences: Abstracts of Scientific Reports], Moscow, 1962, pp 3-8.

31. I. D. Gervaziyeva, and G. I. Lyubovskaya, "The Processes of Stimulation and Inhibition in the Higher Parts of the Central Nervous System and the Function of the Adrenal Cortex as an Expression of Organism Adaptation to Changed Environmental Conditions," in "Materialy"... op. cit., fn 29, pp 94-95.

32. P. D. Gorizontov, "Stress," in "BME" [Great Medical Encyclopedia], Vol 31, pp 608-628.

33. B. B. Kayranskiy, "The Adaptation Syndrome Arising from the Prolonged Effect of High Air Temperature," in "Materialy"... op. cit., fn 29, pp 22-23.

34. R. Lerish, "Osnovy Fiziologicheskoy Khirurgi" [Fundamental of Physiological Surgery], Leningrad, "Medgiz," 1961, 292 pages (translated from French).

35. "Soveshchaniye po Probleme Kortikal'noy Regulyatsii Zhelez Vnutrenney Sekretsii: Tez. Dokl." [Conference on the Problem of Cortical Regulation of Internal Secretion Glands: Abstracts of Reports], Moscow, 1953, 85 pages.

36. I. A. Eskin, "Neurohumoral Regulation of the Adrenocorticotropic Function of the Pituitary Body and Adrenal Cortex," PATOL. FIZIOLOGIYA I EKSPERIM. TERAPIYA, 1957, 1, No 4, pp 10-15.

37. I. A. Eskin, Yu. B. Skebel'skaya, and N. V. Mikhaylova, "The Role of the Nervous System in the Formation and Mechanism of Action of the Hormones of the Pituitary Body," in "Mekhanizmy Deystviya Gormonov" [Mechanisms of Action of the Hormones], Kiev, "Zdorov'ya," 1959, pp 70-74.

38. J. Brady, "The Paleocortex and the Motivation of Behavior," in "Mekhanizmy Tselogo Mozga" [Mechanisms of the Whole Brain], Moscow, "Izd-vo Inostr. Lit.," 1963, pp 138-174.

39. V. S. Deryabin, "Chuvstva, Vlecheniya, Emotsii" [Feelings, Inclinations, and Emotions], Leningrad, "Nauka," 1974, 257 pages.

40. P. Broca, "Anatomic Comparee des Cirkonvolutions Cerebrales. Le Grand Lobe Limbique et la Scissure Limbique dans la Serie des Manniferes," REV. ANTROP. SER., 1878, 21, pp 285-498.

41. P. V. Simonov, "Chto Takoye Emotsiya?" [What Is Emotion?], Moscow, "Nauka," 1966, 93 pages.

42. R. W. Russel (cited by M. Rogovin, "Mental Stress and Mental Disorders," ZHURN. NEVROPATOLOGII I PSIKHIATRII, 1962, 62, Vyp 11, pp 1731-1740).

43. R. C. Davis (cited by M. Rogovin, ibid.).

44. R. Barker, T. Dembo, and K. Levin, "Frustration and Regression: an Experiment with Young Children," in "Studues Topological and Vector Psychology [sic]," Univ. Iowa Stud. Child. Welf., 1941, 18, 1, pp 1-314.

45. S. A. Yeremina, "The Mechanisms of Stress," author's abstract of dissertation for the decree of doctor of medical sciences, Rostov-na-Donu, 1970, 34 pages.

46. S. A. Yeremina, "The Mechanism of Negative Feedback in the Pituitary Body-Adrenal Cortex System in a State of Stress," FIZIOLOGIYA, BIOKHIMIYA I PATOLOGIYA ENDOKRINNOY SISTEMY, 1973, Vyp 3, pp 24-26.

To Chapter 3, Section 2

1. K. K. Ioseliani, and A. L. Narinskaya, "New Methodology for Studying the Consistency of Performance under Time Deficit Conditions," VOYENNO-MED. ZHURN., 1963, No 11, pp 52-54.

2. G. Astardzhiyan, Kh. Radev, Ch. Nachev, and K. Boyev, "Digital Information Device to Analyze Rhythmic Biological Processes of a Certain Class," in "Metody Sbora i Analiza Fiziologicheskoy Informatsii" [Methods of Collecting and Analyzing Physiological Information], Moscow, "Nauka," pp 102-117.

3. V. I. Kudryavtseva, "The Problem of Predicting Mental Fatigue," in "Problemy Upravleniya Funktsiyami Cheloveka i Zhivotnykh" [Problems of Controlling Human and Animal Functions], Moscow, 1973, pp 97-102.

4. U. R. Eydi, "Computer Analysis of Electrocardiograms," in "Vychislitel'nyye Ustroystva v Biologii i Meditsine" [Computer Units in Biology and Medicine], Moscow, "Mir," 1967, pp 153-199.

5. V. P. Shval'b, "Some Simple Methods of Identifying Diagnostically Valuable Signs in Analysis of the EKG," in "Metody Sbora"... op. cit., fn 2, Moscow, "Nauka," 1969, pp 37-46.

6. R.M. Bayevskiy, "Fiziologicheskiye Izmereniya v Kosmose i Problema Ikh Avtomatizatsii" [Physiological Measurements in Space and the Problem of Automating Them], Moscow, "Nauka," 1970, 255 pages.

7. V.I. Kozharinov, N. P. Rasskazov, and A. A. Nemoy, "Cyclical Compression of the Electrocardiogram," in "Aktual'nyye Voprosy Kosmicheskoy Biologii i Meditsiny" [Current Issues of Space Biology and Medicine], Moscow, 1971, pp 137-138.

8. A. M. Kukunov, "One Technique of Automatic Diagnosis and Experience Using It for EKG Analysis," in "Metody Sbora"... op. cit., fn 2, pp 46-50.

9. V.B. Alekseyev, V. M. Akhutin, I. A. Neroslavskiy, and N. K. Syroyegin, "Automatic Operational Analyzer of the EEG Signals of an Operator," in "Avtomaticheskoye Regulirovaniye Fiziologicheskikh Funktsiy v Usloviyakh Patologii" [Automatic Regulation of Physiological Functions in Pathology], Leningrad, 1972, pp 3-5.

10. A. P. Grishanovich, and V. A. Ivkovich, "Method and Device for Measuring the Activity of the EEG of a Human Operator," in "Avtomatizatsiya Mediko-Biologicheskikh Issledovaniy v Oblasti Diagnostiki, Prognozirovaniya i Bioypravleniya" [Automation of Biomedical Research in the Areas of Diagnosis, Prognosis, and Biocontrol], Minsk, 1972, pp 7-10.

11. G. A. Sergeyev, and V. G. Yegrafov, "The Question of Monitoring the State of the Human Operator in an Automatic Control System," VOPR. VOYENNO-INZH. PSIKHOLOGII, 1970, Vyp 3, pp 76-91.

12. V. N. Zhishko, "Automatic Evaluation of the Amplitude and Frequency of Muscle Biopotentials," in "Nekotoryye Problemy Biologicheskoy Kibernetiki" [Some Problems of Biological Cybernetics], Leningrad, "Nauka," 1972, pp 148-153.

13. A. N. Luk'yanov, and V. L. Gaubkin, "Device to Measure Ongoing Values of Pneumogram Parameters," in "Novyye Metody i Apparatura dlya Nauchnykh Issledovaniy v Oblasti Vysshey Nervnoy Deyatel'nosti i Neyrofiziologii" [New Methods and Apparatus for Scientific Research in the Fields of Higher Nervous Activity and Neurophysiology], Moscow, "Nauka," 1973, pp 27-33.

14. G. Warner, "The Use of an Analog Computer to Analyze the Mechanisms of Regulation of Blood Circulation," in "Elektronika i Kibernetika v Biologii i Meditsine" [Electronics and Cybernetics in Biology and Medicine], Moscow, "Izd-vo Inostr. Lit.," 1963, pp 270-272.

15. A. M. Zingerman, "The Influence of the Statistical Description of a System of Signals and Their Values on the Formation of Motor and Vegetative Reactions of the Human Being in the Norm and in Extreme Conditions," in "Ocherki po Prikladnoy Neyrokibernetike" [Essays on Applied Neurocybernetics], Leningrad, "Meditsina," 1973, pp 137-181.

16. B. A. Lushkov, "Study of the State of Emotional Stress of the Operator-Pilot Using an Experimental Model of the Stress Situation," in "Tr. 3 Vsesoyuz. Konf. po Aviats. i Kosm. Meditsine" [Works of the 3rd All-Union Conference on Aviation and Space Medicine], Kaluga, 1969, pp 85-87.

17. R. S. Dadashev, and S. P. Khlebnikov, "Automatic Device for Determining the Functional State of the Human Operator," in "Sistema 'Chelovek i Avtomat'" [The "Man-Machine" System], Moscow, "Nauka," 1965, pp 94-112.

18. V. D. Dipman, "Higher-Speed Analog-Digital Convertor for the Dnepr-1 Computer," ERGONOMIKA, 1972, No 4, pp 226-230.

19. V. I. Kaplan, "Multichannel Programming Units for Physiological Research," BIOL. NAUKI, 1972, 2, pp 131-136.

20. G. V. Abuladze, M. A. Gilinskiy, N. N. Glushkov, and R. Yu. Il'yuchenok, "The Application of Computer Equipment in Neurophysiological Research," in "Avtomatizatsiya Nauchnykh Issledovaniy na Osnove Primeneniya EVM" [Automation of Scientific Research Based on the Application of Computers], Novosibirsk, 1970, pp 6-10.

21. B. N. Malinovskiy, and A. T. Mizernyuk, "System for Automating a Scientific Experiment in the Field of Oncology," in ibid., pp 305-308.

22. V. D. Nebylitsyn, "Osnovnyye Svoystva Nervnoy Sistemy Cheloveka" [Primary Characteristics of the Human Nervous System], Moscow, "Prosveshcheniye," 1966, 381 pages.

23. Yu. A. Gagarin, and V. A. Lebedev, "Psikhologiya i Kosmos" [Psychology and Space], Moscow, "Molodaya Gvardiya," 1976, 207 pages.

24. O. N. Konopkin, "The Dependence of Rate of Information Receipt on Individual Expression of the Primary Characteristics of the Nervous System," in "Tez. Dokl. na 2 S"yezde Psikhologov" [Abstracts of Reports at the 2nd Congress of Psychologists], Moscow, 1963, 176 pages.

25. B. M. Teplov, "Some Questions of the Study of General Types of Higher Nervous Activity in Humans and Animals," in "Tipologicheskiye Osobennosti Vysshey Nervnoy Deyatel'nosti Cheloveka" [Typological Characteristics of Human Higher Nervous Activity], Moscow, "Izd-vo APN RSFSR," 1959, Vol 2, pp 11-12.

26. K. M. Gurevich, "Psychological Questions of Studying the Professional Suitability of Operational Workers in Power Systems," in ibid., Vol 4, 1965, pp 23-33.

27. V. F. Matveyev, "Psychological Manifestations of the Primary Characteristics of the Nervous System in Power System Operators Under Conditions of Hypothetical Emergency," in "Tipologicheskiye Osobennosti"... op. cit., fn 25, Vol 4, pp 34-59.

28. Z. G. Turovskaya, Ye. L. Berezhkovskaya, and E. M. Aleksandrovskaya, "The Individual Style of Work and Psychophysiological Characteristics of Operators in Chemical Production," VOPR. PSIKHOLOGII, 1972, No 5, pp 77-89.

29. P. V. Buryanov, and F. P. Kosmolinskiy, "The Signifiance of Emotions in the Professional Activity of a Pilot," VOYEN.-MED. ZHURN., 1966, No 6, pp 63-65.

30. A. B. Kogan, "The Expression of the Processes of Higher Nervous Activity in the Electrical Potentials of the Cortex during Free Behavior," in "Elektroentsefalograficheskiye Issledovaniya Vysshey Nervnoy Deyatel'nosti" [Electroencephalographic Studies of Higher Nervous Activity], Moscow, "Izd-vo AN SSSR," 1962, pp 42-53.

31. V. V. Suvorova, "Change in the Activity of the Slow Rhythms in the EEG as an Indicator of the State of Discomfort," VOPR. PSIKHOLOGII, 1966, No 2, pp 75-83.

32. R. Arnandes-Peon, "Neurophysiological Correlates of Accustomization and Other Manifastations of Plastic (Internal) Inhibition," in "Elektroentsefalograficheskiye"... op. cit., fn 30, pp 96-109.

33. G. A. Sergeyev, L. P. Pavlova, and A. F. Romanenko, "Statisticheskiye Metody Issledovaniya Elektroentsefalogrammy Cheloveka" [Statistical Methods of Investigating the Human Electroencephalogram], Leningrad, "Nauka," 1968, 207 pages.

34. B. A. Dushkov, A. N. Zolotukhin, F. P. Kosmolinskiy, B. F. Lomov, and V. D. Nebylitsyn, "Study of the State of Emotional Stress of the Operator-Pilot Using an Experimental Model of the Stress Situation," in "Aviatsionnaya i Kosmicheskaya Meditsina" [Aviation and Space Medicine], Moscow, "Nauka," 1969, Vol 1, pp 204-208.

35. A. N. Zolotukhin, and M. T. Nesterenko, "The Frequency of Blinking Movements as an Indicator of the Reliability of the Visual Analyzer of Military Specialists," VOYENNO-MED. ZHURN., 1972, No 2, pp 59-60.

36. N. M. Kulikova, "Change in the EEG of Flight Personnel After Extended Continuous Flights," in "Aviatsionnaya i Kosmicheskaya Meditsina: (Materialy Konf.)" [Aviation and Space Medicine: Conference Materials], edited by V. V. Parin, Moscow, "Nauka," 1963, pp 324-326.

37. V. M. Marishchuk, K. K. Platonov, and Ye. A. Pyatnitskiy, "Napryazhennost' v Polete" [Stress in Flight], Moscow, "Voyenizdat," 1969, 120 pages.

38. G. I. Gurevich, and V. A. Yegorov, "Psychophysiological Problems of Flight Labor and Medical Support for Extended Flights," VOYENNO-MED. ZHURN., 1969, No 3, pp 93-94.

39. W. M. Helvey, G. A. Albright, and A. E. Axalrod, "A Review of Biomedical Monitoring Activities and Report on Studies Made on F-105 Pilots," AEROSPACE MED., 1964, 35, No 1, pp 23-27.

40. G. Drishel', "Dynamics of Regulation of Vegetative Functions," in "Protsessy Regulirovaniya v Biologii" [Regulatory Processes in Biology], Moscow, "Izd-vo Inostr. Lit.," 1960, pp 125-157.

41. K. A. Ivanov-Muromskiy, "Samoregulyatsiya Golovnogo Mozga" [Self-Regulation of the Cerebral Cortex], Kiev, "Nauk. Dumka," 1971, 247 pages.

42. "Ocherki Prikladnoy Neyrokibernetiki" [Essays on Applied Neurocybernetics], Leningrad, "Meditsina," 1973, 232 pages.

43. O. N. Luk'yanova, and L. V. Petrushko, "On the Mechanism of Electro-Anaesthesia," in "Neyrobionika" [Neurobionics], Kiev, "In-t Kibernetiki AN USSR," 1972, pp 85-90.

44. P. V. Bundzen, "Self-Regulation of the Information-Control Functions of the Cerebral Cortex," author's abstract of dissertation for the degree of doctor of medical sciences, Leningrad, 1974, 32 pages.

45. V. V. Gnezditskiy, "Quantitative Evaluation of Reactive Changes in the EEG in the Norm and with Focal Impairments of the Cerebral Cortex," author's abstract of dissertation for the degree of candidate of biological sciences, Moscow, 1974, 27 pages.

46. S. A. Yeremina, "Stress Mechanisms, " author's abstract of dissertation for the degree of doctor of medical sciences," Rostov-na-Donu, 1970, 34 pages.

47. A. M. Zingerman, V. D. Volkova, D. N. Menitskiy, P. V. Bundzen, and B. M. Shishkin, "Typological Characteristics of Adaptation That Determine the Efficiency of Labor Activity," FIZIOL. ZHURN. SSSR, 1974, 60, No 10, pp 1481-1493.

To Chapter 3, Sections 3 and 4

1. V. S. Aver'yanov, and K. S. Tochilov, "The Question of the Dynamics of the Work Capacility of the Operator," NERV. SISTEMA, 1970, Vyp 10, pp 34-42.

2. V. A. Ayrapetyants, "Comparative Description of Physiological Changes in Operators During Stressful and Monotonous Activity," author's abstract of disseration for the degree of candidate of medical sciences, Moscow, 1970, 23 pages.

3. M. K. Akimova, "Formation of a Speed Habit Related to Individual Characteristics of Strength and Lability of Nerve Processes," VOPR. PSIKHOLOGII, 1972, No 2, pp 94-101.

4. G. I. Akinshchikov, "Teloslozheniye i Reaktivnost' Organizma Cheloveka" [Body Build and the Reactivity of the Human Organism], Leningrad, "Izd-vo Leningr. Un-ta," 1969, 91 pages.

5. R. Akof, and F. A. Emeri, "O Tseleustremlennykh Sistemakh" [Goal-Directed Systems], Moscow, "Sov. Radio," 1974, 271 pages.

6. L.S. Aleyev, and Sh. Yu. Yakupov, "Evaluation of the Functional Mobility of the Nerve-Muscle Apparatus of an Operator in an Ergatic System Based on Data from Multichannel Bioelectrical Activity," in "Ergonomika na Sluzhbu Proizvodstvu" [Ergonomics in the Service of Production], Kiev, 1973, pp 11-14.

7. B.G. Anan'yev, "Teoriya Oshchushcheniy" [Theory of Sensations], Leningrad, "Izd-vo Leningr. Un-ta," 1961, 456 pages.

8. P. K. Anokhin, "Biologiya i Neyrofiziologiya Uslovnogo Refleksa" [Biology and the Neurophysiology of the Conditioned Reflex], Moscow, "Meditsina," 1969, 547 pages.

9. Ye. A. Arkhangel'skiy, "Evaluation of the Efficiency of Complex Systems," IZV. LENINGR. ELEKTROTEKH. IN-TA, 1968, Vyp 68, pp 185-189.

10. V. V. Arkhipov, and B. A. Smirnov, "Experimental Study of Operator Activity under Conditions of a Service Queue," VOPR. VOYEN.-INZH. PSIKHOLOGII, 1969, Vyp 2, pp 62-74.

11. V. G. Aseyev, "Criteria of the Monotonousness of Work," VOPR. PSIKHOFIZIOLGII TRUDA, 1971, Vyp 45, pp 26-32.

12. R. M. Bayevskiy, "The Problem of Predicting the State of a Person under Conditions of Space Flight," FIZIOL. ZHURN. SSSR, 1972, 58, No 6, pp 819-827.

13. R. M. Bayevskiy, G. A. Berezina, and V. I. Kudryavtsev, "Modeling the Process of Processing Visual Information into Motor Acts," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 3, Part 2, pp 6-7.

14. R. Barlou, and F. Proshan, "Matematicheskaya Teoriya Nadezhnosti" [Mathematical Theory of Reliability], Moscow, "Sov. Radio," 1969, 488 pages.

15. N. I. Bayandin, and N. S. Bubonin, "Some Models of the Functioning of the Human Operator as an Element of an Automatic Control System," TR. MOSK. ENERG. IN-TA, 1972, Vyp 117, pp 62-68.

16. L. A. Belobzhenskiy, and G. D. Kurzenkov, "The Use of an Information Criterion of Efficiency in Designing Certain 'Man-Machine' Systems," TR. TAGANROG. RADIOTEKHN. IN-TA, 1973, Vyp 8, pp 47-53.

17. N. P. Belyayev, and A. I. Palamarchuk, "Study of Erroneous Actions by Flight Personnel," VOYEN.-MED. ZHURN., 1972, No 10, pp 70-72.

18. G. T. Beregovoy, V. Yu. Krylov, N. V. Krylova, B. F. Lomov, I. B. Solov'yeva, and G. N. Shibanov, "The Problem of the Efficiency of Human Work in Stress Conditions," PROBL. INZH. PSIKHOLOGII I ERGONOMIKA, 1974, Vyp 3, pp 28-30.

19. I. S. Beritov, "Struktura i Funktsii Kory Bol'shogo Mozga" [Structure and Functions of the Cortex of the Large Hemisphere], Moscow, "Nauka," 1969, 532 pages.

20. B. Berns, "Neopredelennost' v Nervnoy Sisteme" [Indeterminacy in the Nervous System], Moscow, "Mir," 1969, 251 pages.

21. N. A. Bernshteyn, "Ocherki po Fiziologii Dvizheniy i Fiziologii Aktivnosti" [Essays on the Physiology of Movement and the Physiology of Activity], Moscow, "Meditsina," 1966, 349 pages.

22. A. A. Bessonov, "Prognozirovaniye Kharakteristik Nadezhnosti Avtomaticheskikh Sistem" [Predicting the Reliability Characteristics of Automatic Systems], Leningrad, "Energiya," 1971, 152 pages.

23. A. M. Blank, V. N. Ryabokon', N. D. Stepanov, and A. S. Tsar'kov, "Model to Simulate Operator Loading with a Time Deficit," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 2, pp 149-150.

24. M. N. Bobneva, "The Problem of Human Reliability (Predictable and Random Failures in the Work of an Operator)," PROBL. INZH. PSIKHOLOGII, 1965, Vyp 2, pp 7-14.

25. V. V. Bogdanov, "Evaluation of the Efficiency of Piloting by the Indicator of Quality of Control and Criteria of Psychophysiological Stress," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 2, pp 74-76.

26. V. A. Bodner, "Avtomaticheskaya Proverka Oborudovaniya Samoletov i Raket" [Automatic Checking of Airplane and Rocket Equipment], Moscow, "Izd-vo Inostr. Lit.," 1962, 216 pages.

27. V. A. Bodrov, "Experimental Study of Emotional Tension in the Operator," VOYEN.-MED. ZHURN., 1973, No 1, pp 70-73.

28. Ye. I. Boyko, "Vremya Reaktsii Cheloveka" [Human Reaction Time], Moscow, "Meditsina," 1964, 440 pages.

29. E. V. Bondarev, B. A. Yegorov, and V. A. Marishchuk, "The Work Capability of the Human Operator Affected by Extreme Factors," EKSPERIM. I PRIKL. PSIKHOLOGIYA, 1971, Vyp 3, pp 46-51.

30. E. V. Bondarev, V. A. Yegorov, and V. A. Kolosov, "The Functional State of the Cardiovascular System of Flight Personnel during Extended Flights," VOYEN.-MED. ZHURN., 1972, pp 65-67.

31. S. V. Borisov, "Mathematical Model of the Processes of Acquiring and Losing Skills," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 2, pp 82-84.

32. S. P. Bocharova, "The Effect of Valuable Information on the Speed of Deciding Design Problems," in "Ob Aktual'nykh Problemakh Eksperimental'nogo Issledovaniya Vremeni Reagirovaniya" [Timely Problems of Experimental Study of Reaction Time], Tartu, 1969, pp 76-80.

33. V. I. Bravovitskiy, A. M. Dovgalo, and A. I. Nikitin, "Human Interaction with the Computer in the Process of Solving Problems," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 70-74.

34. Ye. Ye. Brodetskaya, and I. G. Nedekker, "Criterion of Stationariness in Evaluating the Cardiac Rhythm," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 34-36.

35. R. I. Brusnichkina, "The Question of Evaluating the Complexity of Activity by a Set of Physiological Parameters," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 1, pp 79-80.

36. N. P. Buslenko, V. V. Kalashnikov, and I. N. Kovalenko, "Lektsii po Teorii Slozhnykh Sistem" [Lectures on the Theory of Complex Systems], Moscow, "Sov. Radio," 1973, 439 pages.

37. M. N. Valuyeva, "Proizvol'naya Regulyatsiya Vegetativnykh Funktsiy Organizma" [Random Regulation of the Vegetative Functions of the Organism], Moscow, "Nauka," 1967, 95 pages.

38. B. V. Vasil'yev, "Prognozirovaniye Nadezhnosti i Effektivnosti Radioelektronnykh Ustroyst" [Predicting the Reliability and Efficiency of Radio Electronic Devices], Moscow, "Sov. Radio," 1970, 335 pages.

39. N. Ye. Vvedenskiy, "O Sootnoshenii Mezhdu Vozbuzhdeniyem i Tormozheniyem pri Tetanuse" [The Ratio of Stimulation and Inhibition in Tetanus], Moscow, 1950, pp 36-47 (Selected Works).

40. L. M. Vekker, "The Relationship of the Structure and Localization of the Sensory and Motor Fields in Control Operations," PROBL. INZH. PSIKHOLOGII, 1966, Vyp 4, pp 108-118.

41. V. F. Venda, and V. M. Gordon, "Experimental Study of the Process of Solving Operational Problems," ERGONOMIKA, 1971, Vyp 3, pp 26-38.

42. A. M. Volkov, "Stages of Fatigue in Evaluating the Physical Difficulty and Stress of Labor,"in"Psikhofiziologicheskiye i Esteticheskiye Osnovy NOT" [Psychophysiological and Esthetic Foundations of Scientific Organization of Labor], Moscow, 1971, pp 56-62.

43. A. M. Volkov, A. G. Kalachev, and A. N. Kasatkin, "Model of the Human Operator and Method of Determining the Numerical Values of Its Parameters," TR. MOSK. AVIATS. IN-TA, 1972, Vup 249, pp 22-29.

44. A. D. Voskresenskiy, V. A. Elivanova, and L. Ya. Andriyako, "Evaluating Emotional Tension by a Set of Indicators of the Cardiovascular System," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 3, pp 86-88.

45. U. Vudson, and D. Konover, "Spravochnik po Inzhernoy Psikhologii dlya Inzhenerov i Khudozhnikov-Konstruktorov" [Handbook on Human Factors Engineering for Engineers and Design Artists], Moscow, "Mir," 1968, 518 pages.

46. A. I. Galaktionov, "The Question of Quantitative Evaluation of Complexly Structured Events," PROBL. INZH. PSIKHOLOGII, 1965, Vyp 2, pp 100-120.

47. M. I. Gal'perin, and G. M. Zarakovskiy, "The Operational Psychophysiological Method of A Priori Evaluation of Operator Loading," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 2, pp 56-57.

48. D. V. Gaskarov, T. A. Golinkevich, and A. V. Mozgalevskiy, "Prognozirovaniye Tekhnicheskogo Sostoyaniya i Nadezhnosti Radioelektronnoy Apparatury" [Predicting the Technical State and Reliability of Radio Electronic Equipment], Moscow, "Sov. Radio," 1974, 224 pages.

49. A. A. Genkin, "Identifying a Specific Local Brain Reaction in the EEG During Complex Activity," VOPR. PSIKHOLOGII, 1961, No 6, pp 114-126.

50. A. A. Genkin, "The Average Level of Assymetry in Length of EEG Phases and Rate of Information Processing in the Visual-Motor System," BIOFIZIKA, 10, No 5, pp 868-874.

51. A. A. Genkin, "Some Questions of Decoding EEG Signals in Connection with Diagnosis of Psychophysiological States," in "Metody Sbora i Analiza Informatsii v Fiziologii i Meditsine" [Methods of Collecting and Analyzing Information in Physiology and Medicine], Moscow, 1971, pp 33-42.

52. A. A. Genkin, and V. I. Medvedev, "Prognozirovaniye Psikhofiziologicheskikh Sostoyaniy" [Predicting Psychophysiological States], Leningrad, "Nauka," 1973, 143 pages.

53. V. S. Genes, and Yu. M. Madnevskiy, "Increasing the Reliability of the Labor of Railroad Engineers," in "Ocherki Psikhologii Truda Operatora" [Essays on the Labor Psychology of the Operator], Moscow, 1974, pp 173-186.

54. V. S. Genes, and V. A. Makotchenko, "The Effect of Selection of Indicators of the State of a Function and the Method of Mathematical Processing of Them on the Efficiency of Identifying Transfers in a Biological System," in "Materialy Vtoroy Ukr. Konf. po Bionike" [Materials of the Second Ukrainian Conference on Bionics], Kiev, 1968, pp 54-58.

55. S. G. Gellershteyn, "The Anticipatory Reaction in Pilot Activity," in "Aviatsionnaya i Kosmicheskaya Meditsina" [Aviation and Space Medicine], Moscow, 1963, pp 124-126.

56. B. M. Gerasimov, "Determining the Quantitative Characteristics of Operator Work by Graph Theory Methods," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 4, pp 125-130.

57. V. D. Glezer, and I. I. Tsukkerman, "Informatsiya i Zreniye" [Information and Vision], Moscow, "Izd-vo AN SSSR," 1961, 183 pages.

58. K. K. Glukharev, B. A. Potemkin, Yu. G. Safronov, V. N. Sirenko, and K. V. Frolov, "Eksperimental'nyy Analiz Funktsional'nogo Sostoyaniya Cheloveka-Operatora pri Dlitel'nom Deystvii Vibratsiy" [Experimental Analysis of the Functional State of the Human Operator Exposed to Prolonged Vibration], MASHINOVEDENIYE, 1973, No 2, pp 56-62.

59. N. D. Gordeyev, A. I. Nazarov, and V. G. Romanyuta, "Eye Movement and Control of Traces of Sensory Memory," ERGONOMIKA, 1972, Vyp 4, pp 38-64.

60. V. M. Gordon, P. V. Zinchenko, and V. P. Nevinomyskaya, "Experimental Study of the Process of Information Preparation for Decision-Making," ERGONOMIKA, 1972, Vyp 4, pp 203-226.

61. V. G. Gotsulyak, "Psychological Analysis of the Speed of Information Processing in Women Who Install Automatic Equipment and Assemble Radio Parts," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 65-69.

62. Yu. L. Goshchitskiy, Yu. A. Perikov, A. V. Rulev, and N. G. Goshchitskaya, "The Reliability of the Operator and the Efficiency of the System," TR. LENINGR. ELEKTROTEKHN IN-TA, 1966, Vyp 56, Part 2, pp 151-155.

63. R. S. Grayfer, and I. N. Kartsel', "The Law of Distribution of Operator Errors," TR. TSENTR. N.-I.I PROYEKTNO-TEKHNOL. IN-TA UPR., 1972, Vyp 2, pp 35-41.

64. M. A. Grinevskiy, O. A. Konopkin, and G. A. Stryukov, "Analysis of the State of Expectation in the Work of an Operator in Chemical Production," in "Psikhologicheskiye Voprosy Regulyatsii Deyatel'nosti" [Psychological Questions of Regulating Activity], Moscow, 1973, pp 95-129.

65. A. P. Grishanovich, and V. A. Ivanovich, "Method and Device for Measuring the Activity of an Encephalogram of a Human Operator," in "Avtomatizatsiya Mediko-Biologicheskikh Issledovaniy v Oblasti Diagnostiki, Prognozirovaniye i Bioupravleniya" [Automation of Biomedical Research in the Fields of Diagnosis, Prognosis, and Biocontrol], Minsk, 1972, pp 123-129.

66. A. I. Gubinskiy, and A. B. Tatiyevskiy, "The Reliability of a 'Monitoring System-Human Operator' Combination," STANDARTY I KACHESTVO, 1966, No 7, pp 43-46.

67. A. I. Gubinskiy, and Yu. V. Sukhodol'skiy, "The Concept of Failure Relative to the Human Operator," in "Inzhenernaya Psikhologiya v Priborostroyenii" [Human Factors Engineering in Instrument Making], Moscow, 1967, pp 124-131.

68. A. I. Gubinskiy, "The Reliability and Efficiency of a 'Monitoring System-Human Operator' Combination," in ibid., pp 131-139.

69. K. M. Gurevich, and V. F. Matveyev, "Professional'naya Prigodnost' i Osnovnyye Svoystva Nervnoy Sistemy" [Professional Suitability and the Primary Characteristics of the Nervous System], Moscow, "Nauka," 1970, 272 pages.

70. V. V. Davydov, V. Ye. Ovcharov, and V. A. Ponomarenko, "The Dependence of the Structure of the Pilot's Gathering of Instrument Information in a Semiautomatic Control Regime on the Statistical Characteristics of the Director's Signal," in "Kosmicheskaya Biologiya i Aviokosmicheskaya Meditsina" [Space Biology and Aerospace Medicine], Moscow-Kaluga, 1972, pp 153-156.

71. R. S. Dadashev, "Evaluation of the Functional State of the Human Operator with Automatic Diagnosis," in "Problemy Inzhernoy Psikhologii" [Problems of Human Factors Engineering], Leningrad, 1964, pp 60-61.

72. Yu. P. Darymov, "The Carrying Capacity of the Controller Engaged in Air Traffic Control," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 82-84.

73. V. G. Denisov, and V. F. Onishchenko, "Inzhenernaya Psikhologiya v Aviatsii i Kosmonavtike" [Human Factors Engineering in Aviation and Space Sciences], Moscow, "Mashinostroyeniye," 1972, 313 pages.

74. V. G. Denisov, A. A. Tereshkin, A. V. Skrypets, et al., "One Method of Evaluating the Quality of Functioning of the 'Pilot-Aircraft" System," VOPR. AVIATS. ERGONOMIKI, 1972, Vyp 1, pp 24-26.

75. B. A. Derevyanko, and N. D. Zavalova, "Psychophysiological Characteristics of the Pilot during Instrument Flight," in "Aviatsionnaya"... op. cit., fn. 55, pp 157-159.

76. M. A. Dmitriyeva, "Some Ways to Study the Dependence of the Carrying Capacity of the Human Operator on the Structure of the Operator's Activity," in "Problemy Obshchey Sotsial'noy i Inzhenernoy Psikhologii" [Problems of Social Psychology and Human Factors Engineering], Leningrad, 1966, pp 84-91.

77. V. S. Dorogobed, "Psychophysiological Characteristics of the Emotional Reactions of Cadet Pilots in Extreme Situations," author's abstract of dissertation for the degree of candidate of medical sciences, Moscow, 1974, 21 pages.

78. B. A. Dushkov, Ye. N. Radchenko, and N. A. Zdebskaya, "Investigation of Competing Types of Activity and Mental Tension in the Work of the Operator," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 3, pp 63-65.

79. A. S. Yegorov, and V. P. Zagryadskiy, "Psikhofiziologiya Umstvennogo Truda" [The Psychophysiology of Mental Labor], Leningrad, "Nauka," 1973, 272 pages.

80. V. A. Yegorov, "Change in the Carrying Capacity of the Central Nervous System in the Process of Forming the Skills of Controlling a Pilot Trainer," in "Aviatsionnaya"... op. cit., fn 55, pp 176-178.

81. V. A. Yegorov, "Change in the Rate of Information Processing in the Process of a Pilot's Forming the Skill of Controlling a Trainer," VOYEN.-MED. ZHURN., 1964, No 9, pp 53-62.

82. V. A. Yegorov, "The Carrying Capacity of an Operator as an Indicator of Level of Training and Complexity of the Activity Being Performed," VOPR. PSIKHOLOGII, 1965, No 1, pp 3-9.

83. V. A. Yekimov, V. M. Mironov, and O. V. Rychnikov, "Probability-Information Criteria for Evaluating Operator Activity," TR. LENINGR. IN-TA AVIATS. PRIBOROSTROYENIYA, 1971, Vyp 69, pp 200-208.

84. M. K. Yefimchik, V. A. Ivkovich, and V. I. Kudryavtsev, "The Question of Automatic Monitoring of the State of the Human Operator," in "Upravleniye i Informatsionnyye Protsessy v Zhivoy Prirode" [Control and Information Processes in Living Nature], Moscow, 1971, pp 36-45.

85. A. I. Zhevzhik, and V. G. Kuznetsov, "Methods of Evaluating the Psychophysiological Capabilities of a Pilot," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vu! 2, pp 59-60.

86. V. F. Zhernavkov, V. I. Katkov, E. A. Kozlovskiy, and V. G. Kuznetsov, "Ways to Refine the Objective Evaluation of Operator Activity in Complex Control Systems," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 3, pp 64-66.

87. D. N. Zavalishina, "Analysis of the Process of Solving Discrete Spatial Combinatory Problems Using Motion Pictures of Eye Movement," in "Problemy Inzhenernoy Psikhologii" [Problems of Human Factors Engineering], Leningrad, 1964, pp 149-151.

88. A. V. Zav'yalov, "The Relationship of the Sensitivity of the Aural and the Visual Analyzers," in "Fiziologicheskiye Korrelyaty Psikhicheskoy Deyatel'nosti" [Physiological Correlates of Mental Activity], Kursk, 1970, pp 42-46.

89. V. P. Zaryadskiy, "Norms of Psychophysiological Indicators of the Human Being and Their Significance in Designing 'Man-Machine' Systems," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 156-157.

90. V. P. Zagryadskiy, A. S. Yegorov, and B. N. Yakovets, "The Significance of Indicators of the Functional State of the Organism in Evaluating Mental Work Capability," VOYEN.-MED. ZHURN., 1971, No 9, pp 59-62.

91. A. N. Zaydel', "Elementarnyye Otsenki Oshibok Izmereniy" [Elementary Evaluations of Measurement Errors], Leningrad, "Nauka," 1967, 89 pages.

92. G. M. Zarakovskiy, "Psikhofiziologicheskiy Analiz Trudovoy Deyatel'nosti" [Psychophysiological Analysis of Labor Activity], Moscow, "Nauka," 1966, 114 pages.

93. G. M. Zarakovskiy, B. A. Korolev, V. I. Medvedev, and M. N. Shlayen, "Vvedeniye v Ergonomiku" [Introduction to Ergonomics], Moscow, "Sov. Radio," 1974, 350 pages.

94. A. Zigel', and Dzh. Vol'f, "Modeli Gruppovogo Povedeniya v Sisteme Chelovek-Mashina" [Models of Group Behavior in a Man-Machine System], Moscow, "Mir," 1973, 261 pages.

95. P. B. Zil'berman, "The Emotional Stability of the Operator," in "Ocherki Psikhologii Truda Operatora" [Essays on the Labor Psychology of the Operator], Moscow, 1974, pp 138-173.

97. V. P. Zinchenko, N. I. Mayzel', and L. V. Fatkin, "Operator Activity in the Information Search Mode," VOPR. PSIKHOLOGII, 1965, No 2, pp 3-17.

98. V. P. Zinchenko, and G. L. Smolyan, "Chelovek i Tekhnika" [Man and Machinery], Moscow, "Znaniye," 1965, 43 pages.

99. Z. M. Zolina, "Metody Issledovaniya Fiziologicheskikh Protsessov" [Methods of Investigating Physiological Processes], Moscow, "Meditsina," 1964, 312 pages.

100. Z. M. Zolina, G. M. Gambalidze, and Ye. G. Yampol'skiy, "Comparative Physiological Evaluation of Two Types of Monotonous Activity (Conference and Control Console)," in "Fiziologiya Truda: Tez. Dokl. 6 Vsesoyuz. Konf. po Fiziologii Truda" [Labor Physiology: Abstracts of Reports at the 6th All-Union Conference on Labor Physiology], Moscow, 1973, pp 34-37.

101. A. N. Zolotukhin, and S. Ye. Koshmalyuk, "Psychophysiological Changes in Extreme Conditions," in "Aviatsionnaya i Kosmicheskaya Meditsina" [Aviation and Space Medicine], Moscow, 1969, Vol 1, pp 241-244.

102. A. N. Zolotukhin, S. Ye. Koshmalyuk, and B. A. Dushkov, "The Problem of Operator Reliability in a 'Man-Machine' System," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 17-19.

103. A. N. Zolotukhin, and M. T. Nesterenko, "The Frequency of Eyeblinks as an Indicator of the Reliability of the Visual Analyzer of Military Specialists," VOYEN.-MED. ZHURN., 1972, No 2, pp 59-60.

104. Yu. Ya. Zubarev, and L. G. Filippov, "Analysis of Operator Reliability on the Basis of Sensitivity Theory," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 20-25.

105. V. I. Zubov, "Matematicheskaya Teoriya Nadezhnosti Sistem Massovogo Obsluzhivaniya" [Mathematical Theory of the Reliability of Mass Service Systems], Moscow-Leningrad, "Energiya," 1966, 174 pages.

106. K. A. Ivanov-Muromskiy, "Samoregulyatsiya Golovnogo Mozga" [Self-Regulation of the Cerebral Cortex], Kiev, "Nauk. Dumka," 1971, 246 pages.

107. K. A. Ivanov-Muromskiy, and Yu. V. Paramonov, "Ways to Realize Complex Biotechnical Systems," VISN. AN USSR, 1972, No 11, pp 64-70.

108. A. G. Ivanov-Smolenskiy, "Study of the Combined Work of the First and Second Signaling Systems," ZHURN. VYSSH. NERV. DEYATEL'NOSTI, 1951, 1, Vyp 1, pp 84-92.

109. Ye. P. Il'in, "'Operational Rest' and Optimal Regulation of a Person's Work Capability," in "Ocherki"... op. cit., fn 95, pp 186-207.

110. K. K. Ioseliani, "The Influence of the Stress Factor on the Mental Activity of the Operator-Pilot," in "Materialy Seminara 'Kontrol' Cheloveka-Operatora'" [Materials of the Seminar on "Monitoring the Human Operator"], Moscow, 1970, pp 40-43.

111. K. K. Ioseliani, "The Time Deficit as a Stress Factor in the Mental Activity of an Operator in a 'Man-Aircraft' System," KOSM. BIOLOGIYA I MEDITSINA, 1971, No 5, pp 40-44.

112. K. K. Ioseliani, L. D. Chaynova, and M. Ye. Beletskiy, "The Information Parameters of the Psychophysiological State of Flight Personnel during Work on a Display Unit, " KOSM. BIOLOGIYA I MEDITSINA, 1973, No 3, pp 62-68.

113. P. K. Isakov, "Psychophysiological Characteristics of Low-Altitude Flights," VOYEN.-MED. ZHURN., 1972, No 3, pp 63-65.

114. K.N. Kamkaradze, and A. D. Korotkov, "The Problem of Stochastic Evaluation of the Adaptation of the Human Operator Controlling Dynamic Objects," TR. GRUZ. POLITEKHN. IN-TA, 1970, Vyp 4, pp 71-76.

115. V. T. Karpenko, "Approximate Evaluation of the Reliability of a 'Man-Machine System' in the Design Stage," in "Materialy 2 Vsesoyuz. Simpoz. po Nadezhnosti Kompleks. Sistem 'Chelovek-Tekhnika'" [Materials of the 2nd All-Union Symposium on the Reliability of Complex "Man-Machine" Systems], Leningrad, 1969, Part 1, pp 41-47.

116. A. I. Kikolov, "Umstvenno-Emotsional'noye Napryazheniye za Pul'tom Upravleniya" [Mental-Emotional Tension at the Control Console], Moscow, "Meditsina," 1967, 176 pages.

117. L. A. Kitayev-Smyk, I. P. Neunyvakin, and V. A. Ponomarenko, "The Question of Methods of Evaluating the Psychophysiological State of the Pilot during an Emergency Situation in the Air," in "Problemy Inzhenernoy Psikhologii" [Problems of Human Factors Engineering], Leningrad, 1964, pp 61-62.

118. A. I. Kogan, "Investigation of Criteria for Evaluating Visual Work Capability," ERGONOMIKA, 1971, No 2, pp 5-23.

119. V. T. Kozlova, "The Dependence of Changes in the Variation of Selection Time on the Strength of Nerve Processes," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 3, Part 1, pp 21-24.

120. R. V. Komotskiy, T. V. Sazhina, L. P. Salmanov, V. P. Sal'nitskiy, M. M. Skvortsov, and A. Ye. Chebyshev, "Comprehensive Evaluation of the Activity of a Human Being in a Control System," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 103-106.

121. O. A. Konopkin, and Yu. S. Nazhivin, "The Functional Structure of Self-Regulation of Sensomotor Regulation," in "Materialy Vsesoyuz. Nauch. Sessii NTO im. A. S. Popova" [Materials of the All-Union Scientific Session of the Scientific-Technical Society imeni A. S. Popov], Moscow, 1973, pp 27-32.

122. O. A. Konopkin, and Yu. S. Zhuykov, "The Ability of a Person to Estimate the Probabilistic Characteristics of Alternative Stimuli," in "Psikhologicheskiye Voprosy Regulyatsii Deyatel'nosti" [Psychological Questions of Regulating Activity], Moscow, 1973, pp 154-198.

123. V. V. Kopayev, G. V. Kirillov, and A. A. Alekhina, "Analysis of the Functional State of Operators on the Basis of a Physiological Index," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 3, pp 132-134.

124. A. D. Korotkov, "The Question of Quantitative Evaluation of Sensomotor Adaption of the Human Operator during Tracking," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 3, Part 1, pp 25-28.

125. M. A. Kotik, "Kratkiy Kurs Inzhenernoy Psikhologii" [Short Course in Human Factors Engineering], Tallinn, "Valgus," 1971, 308 pages.

126. M. A. Kotik, "Compensatory Capabilities and the Reliability of Operator Work," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 1, pp 42-44.

127. S. V. Kravkov, "Glaz i Yego Rabota" [The Eye and Its Work], Moscow, "Nauka," 1950, 176 pages.

128. M. Ye. Kramnik, L. F. Solov'yev, and D. M. El'bert, "The Problem of Diagnosing the Level of Alertness of the Human Operator during Monotonous Work," in "Materialy Konf. 'Biol. i Med. Kibernetika'" [Materials of the Conference "Biological and Medical Cybernetics"], Moscow, 1974, Part 5, pp 134-136.

129. M. A. Kremen', "Criteria of Operator Efficiency in a Tracking System," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 3, Part 1, pp 29-31.

130. A. A. Krylov, and A. F. Pakhotov, "The Question of Operator 'Carrying Capacity,'" PROBL. PSIKHOLOGII, 1966, Vyp 4, pp 7-18.

131. A. A. Krylov, "Chelovek v Avtomatizirovannykh Sistemakh Upravleniya" [The Human Being in Automated Control Systems], Leningrad, "Izd-vo Leningr. Un-ta," 1972, 191 pages.

132. A. A. Krylov, "Information Processing in Operator Activity," author's abstract of dissertation for the degree of doctor of psychological sciences, Leningrad, 1972, 33 pages.

133. V. Yu. Krylov, N. V. Krylova, and L. S. Khachaturyants, "Generalized Evaluation of the Quality of Human Activity in Modeling Space Flight," in "Ergaticheskiye Sistemy Upravleniya" [Ergatic Control Systems], Kiev, 1974, pp 28-34.

134. R. Kubo, "Termodinamika" [Thermodynamics], Moscow, "Mir," 1970, 340 pages.

135. V. I. Kudryavtsev, "The Problem of Predicting Mental Fatigue," in "Problemy Upravleniya Funktsiyami Cheloveka i Zhivotnykh" [The Problems of Controlling Human and Animal Functions], Moscow, 1973, pp 47-53.

136. A. N. Lebedev, and V. A. Lutskiy, "Periodicity of Neuronal Activity and Some Hypotheses on Its Functional Significance," in "Statisticheskaya Elektrofiziologiya: Materialy Simpoz." [Statistical Electrophysiology: Symposium Materials], Vilnius, 1968, Part 1, pp 339-358.

137. A. N. Lebedev, and V. A. Lutskiy, "The Rhythms of the Electroencephalogram as a Result of Spontaneous Activity of Neurons with Drifting Thresholds," in "Problemy Biologicheskoy Kibernetiki: Upr. i Inform. Protsessy v Zhivoy Prirode" [Problems of Biological Cybernetics: Control and Information Processes in Living Nature], Moscow, 1971, pp 136-138.

138. A. N. Lebedev, and V. A. Lutskiy, "Calculating the Patterns of Visual Perception by the Frequency Characteristics of the EEG," ERGONOMIKA, 1972, No 4, pp 95-133.

139. V. V. Lebedev, and V. A. Krutov, "Indicators of the Quality of Work of the Human Operator Controlling a Spacecraft," KOSM. BIOLOGIYA I AVIAKOSM. MEDITSINA, 1974, No 6, pp 42-45.

140. Zh. V. Levshinova, "Activation of Psychophysiological Functions Depending on the Changing Rate of Sensomotor Activity," PROBL. INZH. PSIKHOLOGII I ERGNOMIKI, 1974, Vyp 2, pp 250-253.

141. A. N. Leont'yev, "The Formation of Abilities," VOPR. PSIKHOLOGII, 1960, No 1, pp 7-17.

142. A. N. Leont'yev, and D. Yu. Panov, "Psikhologiya i Tekhnicheskiy Progress" [Psychology and Technical Progress], Moscow, "Znaniye," 1962, 60 pages.

143. M. N. Livanov, A. N. Lebedev, and V. A. Krasavin, "The Significance of the 'Spontaneous' Activity of Neurons for Valuable Reactive Processes," ZHURN. VYSSH. NERV. DEYATEL'NOSTI, 1966, 16, No 2, pp 292-297.

144. V. P. Lisenkova, "Some Individual Characteristics of Human Reflection of Time," in "Problemy Obshchey, Sotsial'noy i Inzhenernoy Psikhologii" [Problems of General and Social Psychology and Human Factors Engineering], Leningrad, 1966, pp 52-57.

145. B. F. Lomov, "Chelovek i Tekhnika" [Man and Machinery], Leningrad, "Izd-vo Leningr. Un-ta," 1963, 266 pages.

146. V. G. Loos, "Promyshlennaya Psikhologiya" [Industrial Psychology], Kiev, "Tekhnika," 1974, 229 pages.

147. A. N. Luk'yanov, "The Question of the Possibility of Automatic Monitoring of Operator Attention in a Control System," in "Materialy Konf. 'Inzh. Psikhologiya v Priborostroyenii'" [Materials of the Conference "Human Factors Engineering in Instrument Making"], Leningrad, 1965, pp 32-33.

148. A. N. Luk'yanov, and M. V. Frolov, "Signaly Sostoyaniya Cheloveka-Operatora" [Signals of the State of the Human Operator], Moscow, "Nauka," 1969, 247 pages.

149. I. N. Maydel'man, V. N. Revenko, and B. G. Sarkisyan, "Otobrazheniye Informatsii v Avtomatizirovannykh Sistemakh Upravleniya" [Representation of Information in Automated Control Systems], Moscow, "Sov. Radio," 1972, 296 pages.

150. I. M. Malikov, "Nadezhnost' Sudovoy Elektronnoy Apparatury i Sistem Avtomaticheskogo Upravleniya" [The Reliability of Ship Electronic Equipment and Automatic Control Systems], Leningrad, "Sudostroyeniye," 1967, 315 pages.

151. A. V. Malishevskiy, "The Concept of the 'State' of a Dynamic System," AVTOMATIKA I TELEMEKHANIKA, 1970, No 3, pp 102-107.

152. V. L. Marishchuk, K. K. Platonov, and Ye. A. Aletnitskiy, "Napryazhennost' v Polete" [Stress in Flight], Moscow, "Voyenizdat," 1969, 117 pages.

153. M. A. Matova, "The State of Prostration with Abrupt Change in a Person's Working Conditions," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 173-177.

154. D. Meyster, and Dzh. Rabido, "Inzhenerno-Psikhologicheskaya Otsenka pri Razrabotke Sistem Upravleniya" [Human Factors Engineering Evaluation during Development of Control Systems], Moscow, "Sov. Radio," 1970, 343 pages.

155. A. I. Men'shov, D. M. Nikitin, and G. M. Ronina, "The Efficiency of the Work of a Human Operator with a Full Workload of Different Functions," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 31-36.

156. M. Mesarovich, "Systems Theory and Biology: the Viewpoint of a Theoretician," in "Teoriya Sistem i Biologiya" [Systems Theory and Biology], Moscow, "Mir," 1971, pp 23-31.

157. A. I. Gubinskiy (editor), "Metodicheskiye Rekomendatsii po Otsenke Nadezhnosti i Effektivnosti Kompleksnykh Sistem 'Chelovek-Tekhnika'" [Methodological Recommendations on Evaluating the Reliability and Efficiency of Complex "Man-Machine" Systems], Leningrad, 1971, 138 pages.

158. Ye. A. Mileryan, "Method of Psychological Study of Operator Activity," PROBL. INZH. PSIKHOLOGII, 1965, Vyp 2, pp 51-58.

159. Ye. A. Mileryan, "Operator Reliability in Different Work Regimes," VOPR. PSIKHOLOGII, 1971, No 4, pp 60-69.

160. Ye. A. Mileryan, "Emotional-Volitional Components of Operator Reliability," in "Ocherki Psikhologii Operatorskogo Truda" [Essays on the Psychology of Operator Labor], Moscow, "Nauka," 1974, pp 5-83.

161. Dzh. Miller, Ye. Galanter, and K. Pribram, "Plany i Struktura Povedeniya" [Plans and the Structure of Behavior], Moscow, "Progress," 1964, 238 pages.

162. V. I. Myasnikov, and I. P. Lebedeva, "Electrographic Study of the Efficiency of Receiving Signals in a Competitive Situation," in "Problemy Inzhenernoy Psikhologii" [Problems of Human Factors Engineering], Leningrad, 1964, pp 45-46.

163. V. D. Nebylitsyn, "Study of the Reliability of Work of the Human Operator in Automated Systems," VOPR. PSIKHOLOGII, 1961, No 6, pp 9-18.

164. M. S. Neymark, "Psychological Analysis of Emotional Reactions to Difficulties in Work," in "Voprosy Psikhologii Lichnosti Shkol'nika" [Questions of the Psychology of the Schoolchild's Personality], Moscow, 1961, pp 31-35.

165. A. V. Netushil, V. V. Burlayev, V. I. Glazkov, et al., "Experimental Statistical Method of Constructing a Model of the Human Operator," IZV. VUZOV. SER. ELEKTROMEKHANIKA, 1970, No 4, pp 406-411.

166. V. I. Nikolayev, "Kontrol' Raboty Sudovykh Energeticheskikh Ustanovok" [Monitoring the Work of Ship Power Plants], Leningrad, "Sudostroyeniye," 1965, 239 pages.

167. A. Ye. Ol'shannikova, "Some Physiological Correlates of Emotional States," PROBL. DIFFERENTS. PSIKHOFIZIOLOGII, 1969, Vyp 6, pp 45-54.

168. V. F. Onishchenko, A. A. Volkov, and S. G. Mel'nik, "The Use of the Poly-Effector Method to Evaluate the Psychophysiological Cabailities of an Operator in a 'Man-Automaton' System," in "Problemy"... op. cit., fn 162, p 61.

169. A. S. Osenniy, and V. D. Romanov, "One Technique of Monitoring the Human Operator," KIBERNETIKA I VYCHISL. TEKHNIKA, 1970, Vyp 7, pp 50-53.

170. V. V. Pavlov, "Invariantnost' i Avtonomnost' Nelineynykh Sistem Upravleniya" [Invariance and Self-Sufficiency of Nonlinear Control Systems], Kiev, "Nauk. Dumka," 1971, 271 pages.

171. V. V. Pavlov, "The Ergatic Organism," AVTOMATIKA, 1972, No 4, pp 42-48.

172. V. V. Pavlov, "Some Principles of Ergatic Control Systems and Ways to Realize Them," AVTOMATIKA, 1972, No 3, pp 77-83.

173. I. P. Pavlov, "Physiological Theory of Types of Nervous Systems and Temperaments of TOZh [expansion unknown]," in "Poln. Sobr. Soch." [Complete Works], Moscow, "Medgiz," 1951, Vol 3, Book 2, pp 45-53.

174. D. I. Paleychuk, and V. S. Khominich, "Mathematical Description of the Human Operator in Ergatic Control Systems," KIBERNETIKA I VYCHISL. TEKHNIKA, 1972, Vyp 13, pp 60-64.

175. V. V. Parin, R. M. Bayevskiy, Yu. N. Volkov, and O. G. Gazenko, "Kosmicheskaya Kardiologiya" [Space Cardiology], Leningrad, "Meditsina," 1967, 206 pages.

176. V. V. Parin, and R. M. Bayevskiy, "Vvedeniye v Meditsinskuyu Kibernetiku" [Introduction to Medical Cybernetics], Moscow, "Meditsina," 1968, 298 pages.

177. Ye. V. Petrukhin, "The Possibility of Evaluating Operator Stability by the Operator's Tactics of Work," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 3, pp 89-91.

178. K. K. Platonov, "Voprosy Psikhologii Truda" [Questions of Labor Psychology], Moscow, "Medgiz," 1962, 219 pages.

179. G. A. Platonov, "Chelovek za Pul'tom" [Human Being at the Console], Moscow, "Transport," 1969, 167 pages.

180. V. A. Popov, and L. S. Khachatur'yants, "Reaction of the Organism to the Information Characteristics of a Stimulus," in "Aviatsionnaya i Kosmicheskaya Meditsina" [Aviation and Space Medicine], Moscow, 1963, pp 411-416.

181. A. I. Prokhorov, A. A. Ramyalis, and M. V. Freydina, "Monitoring State as a Method of Evaluating the Influence of Different Factors on the Efficiency of Operator Activity," in "Materialy Seminara 'Kontrol' Sostoyaniya Cheloveka-Operatora'" [Materials from the Seminar "Monitoring the State of the Human Operator"], Moscow-Vilnius, 1971, pp 13-22.

182. A. N. Rayevskiy, and A. V. Antonov, "The Problem of Classifying 'Man-Machine' Systems," PROBL. INZH. PSIKHOLOGII, 1968, Vyp 1, pp 54-58.

183. S. A. Razumov, "Utomleniye i Bor'ba s Nim" [Fatigue and Combating It], Leningrad, "Medgiz," 1954, 72 pages.

184. N. V. Revenko, "Psychological Analysis of the State of the Human Operator in an Experimental Model with Action by an Unexpected Signal," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 178-180.

185. V. I. Rozhdestvenskaya, and I. A. Levochkina, "Functional State during Monotonous Work and Strength of the Nervous System," PROBL. DIFFERENTS. PSIKHOFIZIOLOGII, 1972, Vyp 7, pp 194-223.

186. R. Royg, "Comparison of the Activity of a Human Operator and an Optimal Linear Regulator by the Criterion of Mean Quadratic Error," in "Inzhenernaya Psikhologiya za Rubezhom" [Human Factors Engineering Abraod], Moscow, 1967, pp 384-393.

187. V. F. Rubakhin, "Psikhologicheskiye Osnovy Obrabotki Pervichnoy Informatsii" [Psychological Foundations of Processing Initial Information], Leningrad, "Nauka," 1974, 296 pages.

188. S. L. Rubinshteyn, "Bytiye i Soznaniye" [Existence and Consciousness], Moscow, "Izd-vo AN SSSR," 1957, 328 pages.

189. G. I. Ryl'skiy, "Nekotoryye Metody Optimizatsii Sistemy 'Chelovek-Tekhnika': Preprint Dokl." [A Few Ways to Optimize a "Man-Machine" System: Preprint of Report], Moscow-Leningrad, 1975, 31 pages.

190. I. A. Ryabinin, "Osnovy Teorii i Rascheta Nadezhnosti Sudovykh Elektroenergeticheskikh Sistem" [Fundamentals of the Theory and Calculation of the Reliability of Ship Electric Power Plants], Leningrad, "Sudostroyeniye," 1971, 455 pages.

191. A. I. Sidzhei, and Dzh. Vol'f, "Method of Evaluating Variations of Construction of a 'Man-Machine' System," ZARUBEZH. RADIOELEKTRONIKA, 1962, No 8, pp 45-53.

192. U. M. Siymann, "Multidimensional Analysis of the Dynamics of Several Parameters of the Psychophysiological Acitivity of the Operator," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 1, pp 123-125.

193. P. V. Simonov, "The Role of Emotions in the Adaptive Behavior of Living Systems," VOPR. PSIKHOLOGII, 1956, No 4, pp 75-84.

194. P. V. Simonov, "The Basic (Alpha) Rhythm of the EEG as an Electrographic Expression of Preventive Inhibition of Brain Structures," in "Refleksy Golovnogo Mozga" [Reflexes of the Cerebral Cortex], Moscow, "Nauka," 1965, pp 76-82.

195. P. V. Simonov, "The Dependence of Measurements of Cardiac Rhythm on the Level of Motivation and Pragmatic Indeterminacy of the Environment," in "Nervnoye Napryazheniye i Deyatel'nost' Serdtsa" [Nervous Tension and Cardiac Activity], Moscow, 1969, pp 25-34.

196. B. A. Smirnov, "Investigation of the Sensomotor Reactions of the Operator," in "Ob Aktual'nykh Problemakh Eksperimental'nogo Issledovaniya Vremeni Reagirovaniya" [Timely Problems of Experimental Investigation of Reaction Time], Tartu, 1969, pp 94-98.

196a. B. A. Smirnov, "Evaluating the Degree of Stress of Operator Work," VOPR. VOYEN.-INZH. PSIKHOLOGII, 1970, Vyp 3, pp 112-122.

197. S. D. Smirnov, "Description of Tracking Movements as an Indicator of the Functional States of the Operator," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 3, Part 1, pp 176-177.

198. K. M. Smirnova, and T. Ye. Sazonova, "Evaluating the Degree of Intensity of Labor on a Conveyor Line," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 2, pp 78-79.

199. G. A. Smolyan, "Human Factors Engineering Study of Man-Machine Systems," VOPR. PSIKHOLOGII, 1972, No 5, pp 150-156.

200. Ye. N. Sokolov, "The Orientation Reflex as an Information Regulator," in "Oriyentirovochnyy Refleks v Norme i Patologii" [The Orientation Reflex in the Norm and Pathology], Moscow, 1964, pp 92-98.

201. V. P. Solov'yev, "The Possibility of Using Indicators of the Bioelectric Activity of the Brain and Cardiodynamics for Occupational Selection for Types of Jobs Involving Stress," in "Tez. Dokl. I Vsesoyuz. Simpoz. 'Psikhofiziol. Osnovy Professional. Otbora'" [Abstracts of Reports at the 1st All-Union Symposium on "The Psychophysiological Foundations of Occupational Selection"], Kiev, 1973, pp 17-18.

202. A. V. Solodkova, "The Effect of Emotional States on Operator Thinking," in "Ocherki"... op. cit., fn 160, pp 119-138.

203. B. A. Sosnovskiy, and M. V. Gomezo, "Components of a Sensomotor Skill and Their Statistical Norms," PROBL. INZH. PSIKHOLOGII, 1974, Vyp 1, pp 138-140.

204. S. T. Sosnovskaya, "Psychophysiological Evaluation of Operator Activity in Different Time Regimes," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 2, pp 284-285.

205. B. Ye. Berdicheskiy (editor), "Spravochnik po Nadezhnosti" [Handbook on Reliability], Moscow, "Mir," 1970, Vol 3, 376 pages (translated from English).

206. T. S. Stepanova, K. V. Grachev, and N. A. Snezhko, "Adaptive Regulatory Functions of the Human Brain in the Process of Intensive Learning," in "Materialy Konf. 'Biol. i Med. Kibernetika'" [Materials of the Conference "Biological and Medical Cybernetics"], Moscow, 1974, Part 2, pp 46-50.

207. I. F. Strukov, and V. N. Budko, "The Question of Designing Instruments and Developing Methodologies for Objective Evaluation of Fatigue of the Visual Analyzer," TR. VORONEZH. IN-TA, 1971, Vyp 77, pp 71-80

208. G. A. Stryukov, and M. A. Gritsevskiy, "Human Work Capability," GIGIYENA TRUDA I PROF. ZABOLEVANIYA, 1973, No 10, pp 41-43.

209. P. M. Suvorov, "Monitoring the Activity of the Pilot-Operator Exposed to Prolonged Accelerations," in "Materialy"... op. cit., fn 181, Moscow, 1970, pp 18-21.

210. V. V. Suvorova, "The Relationship Between Indicators of the Electroencephalogram and Individual Vegetative Reaction Characteristics," in "Problemy Differentsial'noy Psikhofiziologii" [Problems of Differential Psychophysiology], Moscow, 1974, pp 243-263.

211. Ye. N. Surkov, "The Question of Certain Characteristics of Performing Operational Tasks in Extreme Conditions," PROBL. OBSHCH., SOTS. I INZH. PSIKHOLOGII, 1968, Vyp 2, pp 84-96.

212. G. V. Sukhodol'skiy, "The Problem of the Reliability and Efficiency of Human Work," in "Voprosy Inzhenernoy Psikhologii v Avtomatizirovannykh Sistemakh Upravlaniya" [Questions of Human Factors Engineering in Automated Control Systems], Leningrad, 1972, pp 14-21.

213. U. M. Siymann, op. cit., fn 192.

213/214. B. M. Tamarchenko, "The Question of the Relationship Between Certain EEG Indicators of Brain Work and Efficiency of Information Processing by the Human Operator," NERV. SISTEMA, 1971, Vyp 2, pp 56-62.

215. V. A. Taran, and A. A. Belov, "Evaluation of the Influence of Certain Emotional Factors on Time of Performance of Operations in an Ergatic Process," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 52-57.

216. V. A. Taran, A. D. Korotkov, Yu. N. Kafanov, A. A. Belov, and I. G. Shramkov, "The Possibilities of Quantitative Evaluations of the Functioning of Closed Control Systems with Human Operators," MEKHANIKA MASHIN, 1971, Vyp 27/28, pp 148-161.

217. O. K. Tikhomirov, Ya. Ya. Belik, E. D. Poznyanskaya, and N. Kh. Turchenkov, "Experiment with the Application of Information Theory to Analysis of the Process of Human Deciding of Mental Problems," VOPR. PSIKHOLOGII, 1964, No 4, pp 21-39.

218. V. N. Trofimov, "The Information Method of Evaluating the Efficiency of Ergatic Systems," in "Ergaticheskiye Sistemy" [Ergatic Systems], Kiev, 1974, pp 91-97.

219. L. N. Uznadze, "Psikhologicheskiye Issledovaniya" [Psychological Research], Moscow, "Nauka," 1966, 452 pages.

220. L. V. Fatkin, "Application of the Theory of Mass Service in Human Factors Engineering Problems," in "Materialy Pervoy Leningr. Konf. po Inzh. Psikhologii" [Materials of the First Leningrad Conference on Human Factors Engineering], Leningrad, 1964, pp 24-27.

221. A. L. Farberov, "Investigation and Correlation of the Static-Dynamic Characteristics of 'Operator-Technical Device' Systems," author's abstract of dissertation for the degree of candidate of technical sciences, Moscow, 1973, 18 pages.

222. P. Fitts, and Dzh. Petterson, "Carrying Capacity of Discrete Motor Reactions," in "Inzhenernaya Psikhologiya" op. cit., fn 186, pp 408-425.

223. L. Fogel', "Intellectual Levels of Decisions," in "Inzhenernaya Psikhologiya" [Human Factors Engineering], Moscow, 1964, pp 54-63 (translated from English).

224. Yu. G. Fokin, "Nadezhnost' pri Ekspluatatsii Tekhnicheskikh Sredstv" [Reliability in the Operation of Technical Equipment], Moscow, "Oborongiz," 1970, 224 pages.

225. P. Fraisse, and J. Piaget,"Eksperimental'naya Psikhologiya" [Experimental Psychology], Moscow, "Progress," 1970, 197 pages.

226. V. M. Frolov, "Urovni Funktsionirovaniya Fiziologichesikh Sistem i Metody Ikh Opredeleniya" [Levels of Functioning of Physiological Systems and Ways to Determine Them], Leningrad, "Meditsina," 1972, 173 pages.

227. V. M. Frolov, "Automatic Monitoring of Changes in the Emotional State of the Operator in a 'Man-Machine' System, in "Materialy Konf. 'Inzh. Psikhologiya v Priborostroyenii'" [Materials of the Conference "Human Factors Engineering in Instrument Making"], Leningrad, 1965, pp 33-34.

228. Ye. V. Khrunov, L. S. Khachatur'yants, V. A. Popov, and Ye. A. Ivanov, "Chelovek-Operator v Kosmicheskom Polete" [The Human Operator in Space Flight], Moscow, "Mashinostroyeniye," 1974, 399 pages.

229. L. D. Chaynova, "The Influence of the Functional State of the Sensitivity of the Visual Analyzer," in "Materialy" op. cit., fn 181, pp 33-38.

230. L. D. Chaynova, "The Character of Change in Certain Psychophysiological Functions of the Human Being Related to Visual Activity in a Situation of Acute Time Shortage," PROBL. INZH. PSIKHOLOGII, 1971, Vyp 2, pp 197-201.

231. A. V. Chubarov, and V. V. Petelina, "Evaluating the Quality of Work by a Human Operator According to the EEG," FIZIOL. ZHURN. SSSR, 1971, 27, No 3, pp 45-53.

232. D. Shadrinov, and T. A. Korneyeva, "Classification of Types of Correcting Information from the Standpoint of Energy-Information Relations," PROBL. INZH. PSIKHOLOGII I ERGONOMIKI, 1974, Vyp 1, pp 68-70.

233. P. G. Shamrov, "The Question of Evaluating the Psychophysiological Capabilities of the Operator in a 'Man-Machine' System," PROBL. INZH. PSIKHOLOGII, 1966, Vyp 4, pp 171-186.

234. V. I. Ekazeli, "Some Aspects of Optimal Interaction of the Human Being and the Machine in Complex Control Systems," in "Automatizatsiya Proizvodstvennykh Protsessov v Promyshlennosti" [Automation of Production Processes in Industry], Rustavi, 1972, pp 56-62.

235. D. G. El'kin, "Counting Time Through a Skin Analyzer," PROBL. INZH. PSIKHOLOGII, 1972, Vyp 3, Part 1, pp 183-184.

236. M. A. Epler, and P. Kh. Kingisepp, "The Correlation between Amplitude of an Electrocardiogram Wave and the Length of the Cardiac Cycle," in "Statisticheskaya Elektrofiziologiya" [Statistical Electrophysiology], Vilnius, 1968, Part 2, pp 35-39.

237. W. R. Ashby, "Vvedeniye v Kibernetiku" [Introduction to Cybernetics], Moscow, "Izd-vo Inostr. Lit.," 1959, 432 pages.

238. W. R. Ashby, "Konstruktsiya Mozga. Proiskhozhdeniye Adaptivnogo Povedeniya" [The Structure of the Brain. The Origin of Adaptive Behavior], Moscow, "Mir," 1964, 411 pages.

239. V. S. Yurkevich, "Self-Regulation as a Factor in Overall Giftedness," in "Problemy Obshchey i Differentsial'noy Psikhologii" [Problems of General and Differential Psychology], 1972, pp 233-250.

240. G. A. Bekey, "The Human Operator as a Sampled Data System," INST. RADIO. ENG. TRANS. HUMAN FACTORS IN ELECTRON., 1962, No 3, pp 60-71.

241. G. E. Cooper, "Understanding and Interpreting Pilot Opening," AURON. ENG. REV., 1957, No 3, pp 47-51.

242. I. E. Crave, "Pilot's Fatigue and Emotional Problems," FLIGHT MAG., 1972, 61, No 2, pp 161-170.

243. P. M. Fitts, and R. E. Tones, "Analysis of Factors Contributing to the 460 'Pilot Error' Experiences in Operating Aircraft Controls," in "Selected Papers on 'Human Factors,'" New York, 1961, pp 332-334.

244. I. I. Elkind, "A Survey of the Development of Models for the Human Controller," in "Progress in Astronautics and Acronautics," London, 1964, Vol 13, pp 34-42.

245. P. Fraisse, "Correlations between Electroencephalographic Patterns and Speed of Visual Perception," EEG AND CLIN. NEUROPHYSIOL., 1960, 12, No 1, pp 634-670.

246. L. Fravis, and E. Onanian, "The Effect of Memoring [sic, possibly should by "Memory"] upon the α-Rhythm," EEG AND CLIN. NEUROPHYSIOL., 1954, 6, No 2, pp 407-412.

247. S. Criew, D. R. Davis, and A. C. Treacher, "Heart Rate During Augilance [sic] Performance," NATURE, 1963, 200, No 4910, pp 132-141.

248. H. Gastaut, and I. Bert, "EEG Changes during Cinematographic Presentation (Moving Picture Activation of the EEG)," EEG AND CLIN. NEUROPHYSIOL., 1954, 6, No 3, pp 68-72.

249. M. A. Grodsky, "Rick [sic, possibly "Risk"], AEROSPACE ENG., 1962, 21, No 1, pp 28-32.

250. H. V. Hale, B. O. Hartman, and D. A. Harris, "Physiologic Stress during 50-Hour Doublrew [sic, possibly "Double-Crew"] Missions in C-141 Aircraft," AEROSPACE MED., 1972, 43, No 3, pp 138-148.

251. V. Hammerton, "Violent Exercise and Cognitive Tasks," ERGONOMICS, 1971, 14, No 2, pp 241-250.

252. F. O. Hemming, "Aircraft Accidents and Human Factors," AEROSPACE MED., 1973, 44, No 6, pp 682-684.

253. W. E. Hick, "On the Rate of Gain in Information Quart [sic]," J. EXP. PHYSIOL., 1952, 4, pp 76-83.

254. P. McNemar, "Twin Recembences [sic] in Motor Skills and the Effect of Practice Thereon," J. GENETIC PSYCHOL., 1933, 17, No 1, pp 427-434.

255. R. K. Mehra, and I. S. Tyles, "Modeling the Human Operator under Stress Conditions Using Systems Identification," in "13th Joint Automat. Control Conf. Prepr. Techn. Pap.," New York, 1972, pp 137-144.

256. M. D. Mesarovic, R. Erlandson, D. Macko, and D. Fleming, "Satisfaction Principle in Modeling Biological Function. Do Biological Systems Optimize or Satisfy?" KYBERNATES, 1973, 2, No 2, pp 74-80.

257. A. N. Nicholson, L. E. Hill, R. D. Berland, and W. I. Zanowski, "Influence of Workload on the Neurological State of a Pilot during the Approach and Landing," AEROSPACE MED., 1973, 44, No 2, pp 631-642.

258. L. Orloci, "Ranking Characters by Dispersion Criterion," NATURE, 1973, 244, No 5415, pp 35-47.

259. I. W. Senders, "The Human Operator as a Monitor and Controller of Multi-Degree-of-Freedom Systems," in "4th Nat. Sump. on Human Factors in Electron.," 1963, pp 74-86.

260. D. O. Wolter, I. M. Rhodes, and W. R. Adey, "Discriminating among States of Consciousness by EEGT Measurement," AEROSPACE MED., 1967, No 4, pp 147-160.

To Chapter 4, Section 3

1. A. G. Zdravomyslov, V. P. Rozhin, and V. A. Yadov (editors), "Chelovek i Yego Rabota" [The Human Being and Work], Moscow, "Mysl'," 1965, 250 pages.

2. V. E. Shlyapentokh, "Sotsiologiya dlya Vsekh" [Sociology for Everyone], Moscow, "Sov. Rossiya," 1970, 250 pages.

3. V. N. Shubkin, "Sotsiologicheskiye Opyty" [Sociological Experiments], Moscow, "Mysl'," 1970, 287 pages.

4. V. A. Yadov, "Sotsiologicheskiye Issledovaniya (Metodologiya, Programma, Metody)" [Sociological Research (Methodology, Program and Techniques)], Moscow, "Nauka," 1972, 239 pages.

5. G. M. Andreyev (editor), "Lektsii po Metodike Konkretnykh Sotsiologicheskikh Issledovaniy" [Lectures on the Methodology of Concrete Sociological Research], Moscow, "Izd-vo Mosk. Un-ta," 1972, 200 pages.

6. S. I. Ozhegov, "Slovar' Russkogo Yazyka" [Dictionary of the Russian Language], Moscow, "Sov. Entsiklopediya," 1973, 847 pages.

To Chapter 5

1. V. N. Sadovskiy, "System," in "BSE" [Great Soviet Encyclopedia], 3rd ed, Moscow, "Sov. Entsiklopediya," 1976, Vol 23, pp 1376-1380.

2. V. P. Zinchenko, "Vvedeniye v Ergonomiku" [Introduction to Ergonomics], Moscow, "Sov. Radio," 1974, 351 pages.

3. G. V. Sukhodol'skiy, "Strukturno-Algoritmicheskiy Analiz i Sintez Deyatel'nosti" [Structural-Algorithmic Analysis and Synthesis of Activity], Leningrad, "Izd-vo Leningr. Un-ta," 1976, 120 pages.

4. G. M. Zarakovskiy, "Psikhofiziologicheskiy Analiz Trudovoy Deyatel'nosti" [Psychophysiological Analysis of Labor Activity], Moscow, "Nauka," 1966, 114 pages.

5. K. V. Lyudvichek, and V. Ye. Alekseyev, "Using Multifactor Mathematical Models of Operator Activity to Analyze and Evaluate the Processes of Operating Complex Ergatic Systems," in "Ergonomika na Sluzhbe Proizvodstva" [Ergonomics in the Service of Production], Kiev, "O-vo 'Znaniye' USSR," 1978, pp 5-6.

6. V. M. Akhutin, and A. I. Naftul'yev, "Mathematical Modeling of the Activity of the Human Operator in Development of Ergatic Systems," CHELOVEK I OBSHCHESTVO, 1973, Vyp 11, pp 245-254.

7. B. F. Lomov, V. V. Rubakhin, and V. F. Venda (editors), "Inzhenernaya Psikhologiya. Teoriya, Metodologiya, Prakticheskoye Primeneniye" [Human Factors Engineering. Theory, Methodology, and Practical Application], Moscow, "Nauka," 1977, 304 pages.

8. A. Zigel', and Dzh. Vol'f, "Model' Gruppovogo Povedeniya v Sisteme 'Chelovek-Mashina' s Uchetom Psikhosotsial'nykh i Proizvodstvennykh Faktorov" [Model of Group Behavior in a "Man-Machine" System Considering Psychosocial and Production Factors], Moscow, "Mir," 1973, 261 pages.

9. V. A. Myasnikov, and V. P. Petrov (editors), "Aviatsionnyye Tsifrovyye Sistemy Kontrolya i Upravleniya" [Aviation Digital Monitoring and Control Systems], Leningrad, "Mashinostroyeniye," 1976, 607 pages.

10. B. Ye. Berdichevskiy (editor), "Spravochnik po Nadezhnosti" [Handbook on Reliability], Moscow, "Mir," 1971, Vol 3, 376 pages (translated from English).

11. D. Louli, and A. Makswell, "Faktornyy Analiz kak Statisticheskiy Metod" [Factor Analysis as a Statistical Method], Moscow, "Mir," 1968, 101 pages.

12. "Sbornik Nauchnykh Programm na FORTRANE. Statistika" [Collection of Scientific Programs in FORTRAN. Statistics], Moscow, "Statistika," 1974, Vyp 1, 316 pages (translated from English, USA).

13. V. Ye. Alekseyev, V. I. Garkin, I. A. Lyudvichek, et a., "Device for Using the Psychophysiological Capabilities of the Operator," author's certificate No 643957, published in B.I., 1979, No 3.

14. Yu. A. Abramov, V. Ye. Alekseyev, K. V. Kyudvichek, et al., "Control System Operator Trainer," author's certificate No 590805 (USSR), published in B.I., 1978, No 4.

15. Ibid.

16. "Expert Evaluation," in BSE [Great Soviet Encyclopedia], 2nd ed., 1957, Vol 48, p 412.

17. "Technical Expert Evaluation," in ibid., pp 413-414.

18. V. Ya. Dubrovskiy, and L. P. Shchedrovitskiy, "Problemy Sistemnogo Inzhenerno-Psikhologicheskogo Proyektirovaniya" [Problems of Systems Human Factors Engineering Design], Moscow, "Izd-vo Mos. Un-ta," 1971, 94 pages.

19. D. Meyster, and Dzh. Rabido, "Inzhenerno-Psikhologicheskaya Otsenko pri Razrabotke Sistem Upravleniya" [Human Factors Engineering Evaluation in Development of Control Systems], Moscow, "Sov. Radio," 1970, 343 pages.

20. A. A. Ayvazov, Z. I. Bashayeva, and O. V. Staroverov, "Klassifikatsiya Mnogomernykh Nablyudeniy" [Classification of Multidimensional Observations], Moscow, "Statistika," 1974, 240 pages.

To Chapter 6

1. V. S. Gaydenko, "Osnovy Postroyeniya Avtomatizirovannykh Sistem Kontrolya Slozhnykh Ob"yektov" [Fundamentals of Constructing Automated Systems to Monitor Complex Objects], Moscow, "Energiya," 1969, 230 pages.

2. N. I. Chuprikova, "Study of Evoked Potentials in the Human Being," VOPR. PSIKHOLOGII, 1967, No 1, pp 54-61.

3. N. I. Bekhtereva, "Neyrofiziologicheskiye Aspekty Psikhicheskoy Deyatel'nosti Cheloveka" [Neurophysiological Aspects of Human Mental Activity], Leningrad, "Meditsina," 1971, 117 pages.

4. A. N. Luk'yanov, and M. V. Frolov, "Signaly Sostoyaniya Operatora" [Signals of Operator State], Moscow, "Nauka," 1969, 246 pages.

5. Ye. N. Boyko, "Vremya Reaktsii Cheloveka" [Human Reaction Time], Moscow, "Meditsina," 1962, 440 pages.

6. A. A. Sergeyev, "Vliyaniye Peregruzok na Organizm Letchika" [The Effect of Overloads on the Pilot's Organism], Moscow, "Voyenizdat," 1954, 343 pages.

7. I.P. Popov, V. V. Borshchenko, and F. A. Vasinich, "Investigation of the State of Human Skin with Prolonged Restriction on Its Hygienic Treatment," PROBL. KOSMICH. BIOLOGII, 1967, Vyp 7, pp 413-420.

8. L. A. Kazaryan, "Instrument for Automatic Measurement of Arterial Pressure," in "Sovremennyye Pribory i Tekhnika Fiziologicheskogo Eksperimenta" [Contemporary Instruments and Equipment for Physiological Experiments], Moscow, "Nauka," 1969, 137 pages.

9. "Small Sensor for Measuring the Per-Minute Volume of Respiration under Flight Conditions," RZH BIOLOGIYA. FIZIOLOGIYA CHELOVEKA I ZHIVOTNYKH, 1971, 3N840.

10. L. Kharmon (editor), "Paspoznavaniye Obrazov pri Pomoshchi TsVM" [Image Recognition Using Digital Computers], Moscow, "Mir," 1974, 274 pages.

11. R. S. Dadashev, and S. P. Khlebnikov, "Automatic Device for Determining the Functional State of the Human Operator," in "Sistema 'Chelovek i Avtomat'" [The "Human-Automaton" System], Moscow, 1965, pp 86-93.

12. A. A. Genkin, and G. M. Zarakovskiy, "Automation of Diagnosis of the Functional States of the Organism by EEG Data," PROBL. INZH. PSIKHOLOGII, 1966, Vyp 4, pp 190-206.

13. Yu. I. Neymark (editor), "Raspoznavaniye Obrazov i Meditsinskaya Diagnostika" [Image Recognition and Medical Diagnosis], Moscow, "Nauka," 1972, 384 pages.

14. M. B. Tarmakovskiy, A. G. Frantsuz, B. V. Kozlovskiy, et al., "Statistical Methods of Evaluating the Usefulness of Signs in Solving the Problems of Classifying Electrograms," in "Statisticheskaya Elektrofiziologiya: Materialy Simpoz., Palanga, Avgust 1968" [Statistical Electrophysiology: Materials of the Symposium in Palanga in August, 1968], Palanga, 1968, pp 84-92.

15. V. N. Fomin, "Matematicheskaya Teoriya Obuchayemykh Opoznayushchikh Sistem" [Mathematical Theory of Instructable Recognition Systems], Leningrad, "Izd-vo Leningr. Un-ta," 1976, 234 pages.

16. K. K. Valuzhis, I. O. Levitman, and E. A. Ernitskite, "Compact Representation of a Set of Electrograms," DAN SSSR, 1967, No 3, Vol 177, pp 186-189.

17. Kh. V. Pinberger, "Analysis of Electrograms on the Computer," in "Vychislitel'nyye Ustroystva v Biologii i Meditsine" [Computers in Biology and Medicine], Moscow, "Mir," 1967, pp 113-145.

18. R. I. Utyamyshev, "Radioelektronnaya Apparatura dlya Issledovaniya Fiziologicheskikh Protsessov" [Radioelectronic Equipment for Studying Physiological Processes], Moscow, "Energiya," 1969, 184 pages.

19. N. V. Pozin, "Modelirovaniye Neyronnykh Struktur" [Modeling Neuron Structures], Moscow, "Nauka," 1971, 281 pages.

20. B. Uidrou, Dzh. R. Glover, D. M. Makkul, et al., "Adaptive Compensators of Noise. Principles of Construction and Application, TI ER, 1975, No 12, pp 69-98.

21. V. A. Likharev, and V. P. Tebyakikh, "Methods of Instructing Systems That Solve Problems of Image Recognition and Detecting Signals against a Noise Background," ZARUBEZH. RADIOELETRONIKA, 1967, No 11, pp 59-72.

22. "The Application of Field Transistors in Hybrid Integrated Circuits Based on Them in Radioelectronic Equipment," POLUPROVODNIKOVYYE PRIBORY, Ser. 2, 1975, Vyp 1, p 38.

23. L. S. Gutkin, "Teoriya Optimal'nykh Metodov Padiopriema pri Flyuktuatsionnykh Pomekhakh" [Theory of Optimal Methods of Radio Receiving with Fluctuating Noise], Moscow, "Sov. Radio," 1972, 446 pages.

24. M. I. Maklyukov, "Inzhenernyy Sintez Aktivnykh RC-Fil'trov Nizkikh i Infrakrasnykh Chastot" [Engineering Synthesis of Active RC-Filters for Low and Infrared Frequencies], Moscow, "Energiya," 1971, 184 pages.

25. V. P. Loginov, "Walsh Functions and Their Area of Application," ZARUBEZH. RADIOELEKTRONIKA, 1973, No 8, pp 73-101.

26. A. N. Kolmogorov, and S. F. Fomin, "Elementy Teorii Funktsiy i Funktsional'nogo Analiza" [Elements of the Theory of Functions and Functional Analysis], Moscow, "Nauka," 1971, 436 pages.

27. Luks and Dreyk, "A Simple Adaptive Machine for Detecting Failures," ZARUBEZH. RADIOELEKTRONIKA, 1968, No 6, pp 65-74.

28. V. M. Loginov, G. V. Tsepkov, and P. I. Chinayev, "Ekonomicheskoye Kodirovaniye" [Economic Coding], Kiev, "Tekhnika," 1976, 173 pages.

29. P. I. Sochivko, "Elektricheskiye Modeli Neyronov" [Electrical Models of Neurons], Moscow-Leningrad, "Energiya," 1965, 87 pages.

30. V. I. Kiy, and G. F. Kolesnikov, "Funktsional'noye Modelirovaniye Nervnoy Sistemy" [Functional Model of the Nervous System], Moscow, "Meditsina," 1969, 236 pages.

31. Ya. V. Tsypkin, "Osnovy Teorii Obuchayushchikhsya Sistem" [Fundamentals of the Theory of Learning Systems], Moscow, "Nauka," 1970, 251 pages.

32. B. Katts, "Nerv, Myshtsa, Sinaps" [Nerve, Muscle, Synapse], Moscow, "Mir," 1971, 164 pages.

33. N. I. Chinayev, K. A. Ivanov-Muromskiy, A. D. Ryabinin, et al., "Transformation of Continuous Functions Using Artifical Neuron Nets," KIBERNETIKA I VYCHISL. TEKHNIKA, 1970, Vyp 4, pp 131-139.

34. A. M. Shkvar, A. I. Shevchenko, D. I. Chus', and A. A. Silakov, "Complete Monitoring of Dynamic Systems Using Neuron Structures," in "Neyrobionika" [Neurobionics], Kiev, "In-t Kibernetiki AN USSR," 1974, pp 77-84.

35. A. D. Ryabinin, O. A. Nezhivov, A. M. Shkvar, et al., "Comparison Devices of Automated Monitoring Systems Based on Neuron Elements," in ibid., pp 72-77.

36. C. R. Paul, and R. W. Koch, "On Piecewise-Linear Basis Functions and Piecewise-Linear Signal Expansions," IEEE TRANS. ACOUST. SPEECH AND SIGNAL PROCESS, 1974, 22, No 4, pp 263-268.

To Chapter 7.

1. N. P. Bekhtereva, P. V. Bundzen, and Yu. L. Gogolitsyn, "Mozgovyye Kody Psikhicheskoy Deyatel'nosti" [Brain Codes of Meantal Activity], Leningrad, "Nauka," 168 pages.

2. L. N. Fitsner, "Biologicheskiye Sistemy" [Biological Systems], Moscow, "Nauka," 1977, 135 pages.

3. F. S. Grodings, "Control Theory and Biological Systems," New York-London, 1963, 253 pages.

4. P. V. Bundzen, and B. M. Shishkin, "Study of the Organization of Autoregulatory Processes in the Activity of the Cerebral Cortex," in "Nekotoryye Problemy Biologicheskoy Kibernetiki" [Some Problems of Biological Cybernetics], Leningrad, "Nauka," pp 38-43.

5. K.A. Ivanov-Muromskiy, "Samoregulyatsiya Golovnogo Mozga" [Self-Regulation of the Cerebral Cortex], Kiev, "Nauk. Dumka," 1971, 248 pages.

6. F.Grodings, "Teoriya Regulirovaniya i Biologicheskiye Sistemy" [Regulation Theory and Biological Systems], Moscow, "Mir," 1966, 254 pages.

7. K.K. Anokhin, "Biologiya i Neyrofiziologiya Uslovnogo Refleksa" [Biology and Neurophysiology of the Conditioned Reflex], Moscow, "Meditsina," 1968, 547 pages.

8. V.V. Trubachev, and P. B. Suvorov, "Study of the Neurogenic Mechanisms of Self-Regulation of the Functional State of the Brain Using External Feedback," in "Nekotoryye Problemy" op. cit., fn 4, pp 43-54.

9. L.Milsum, "Analiz Biologicheskikh Sistem Upravleniya" [Analysis of Biological Control Systems], Moscow, "Mir," 1968, 501 pages.

10. N.N. Peysakhov, "Samoregulyatsiya i Tipologicheskiye Svoystva Nervnoy Sistemy" [Self-Regulation and Typological Characteristics of the Nervous System], Kazan', "Izd-vo Kaz. Un-ta," 1974, 252 pages.

11. D.N. Menitskiy (editor), "Ocherki Prikladnoy Neyrokibernetiki" [Essays on Applied Neurocybernetics], Leningrad, "Meditsina," 1973, 232 pages.

12. N.N. Savilevskiy, "Theoretical and Physiological Methods of Controlled Experimentation as a Method of Systems Analysis," VOPR. KIBERNETIKI, 1975, Vyp 24, pp 113-119.

13. N.K. Maslov, V. O. Ostrovskiy, and V. B. Slezin, "Short Survey of the Basic Characteristics and Properties of Biological Control Systems," in "Nekotoryye Problemy" op. cit., fn 4, pp 13-21.

14. K. A. Ivanov-Muromskiy, "Self-Regulatory Processes of the Cerebral Cortex in Different Functional States," PROBL. NEYROKIBERNETIKI, 1974, 5, Part 2, pp 66-78.

15. O. Zager, "Self-Regulation Mechanisms in Cortical-Subcortical Relations," in "Refleksy Golovnogo Mozga" [Reflexes of the Cerebral Cortex], Moscow, 1965, pp 218-226.

16. P. V. Bundzen, "Self-Regulation of the Information Control Functions of the Human Cerebral Cortex," author's abstract of dissertation for the degree of doctor of medical sciences, Leningrad, 1974, 27 pages.

16. Ye. A. Voytinskiy, and V. A. Pryanishnikov, "Study of the Brain as a Self-Regulatory System to Record the EEG during Afferent Stimulation," in "Tez. Dokl. 22 Nauch.-Tekh. Konf., Posvyshchen. 50-letiyu Sov. Vlasti i Dnyu Radio" [Abstracts of Reports at the 22nd Scientific-Technical Conference, Dedicated to the 50th Anniversary of Soviet Power and Radio Day], Leningrad, 1967, p 42.

18. A. A. Genkin, D. P. Danilin, and L. P. Latash, "The Level of Assymetry of the Phase Length of Oscillations in the EEG of a Narcolepsy Victim," ZHURN. VYSSH.NERV. DEYATEL'NOSTI, 1968, 18, No 1, pp 87-103.

19. P. Flory, B. Steresky-Wolanki, and U. Hofy, "Observatii Asupra Homeostazici Neuro-Psihice," ST. CERC. FIZIOL., 1966, 11, No 4, pp 335-348.

20. G. I. Polyakov, "O Printsipakh Neyronnoy Organizatsii Mozga" [Principles of Neuron Organization of the Brain], Moscow, "Izd-vo Mosk. Un-ta," 1965, 166 pages.

21. "Teoriya i Praktika Avtomaticheskikh Sistem" [Theory and Practice of Automated Systems], Moscow, "Nauka," 1964, 243 pages.

22. V. M. Khayutin, "Development of Ideas of the Function of the Cardio-Phthalic Zones and the Synocarotid Zones," FIZIOL. ZHURN. SSSR, 1967, No 12, pp 1469-1475.

23. A. A. Ukhtomskiy, "Sobr. Sochineniy" [Collected Works], 6 Vol, Leningrad, 1954, Vol 5, 262 pages.

24. N. M. Amosov, V. A. Lishchuk, S. A. Patskina, et al., "Samoregulyatsiya Serdtsa" [Self-Regulation of the Heart], Kiev, "Nauk. Dumka," 1969, 160 pages.

25. K. A. Ivanov-Muromskiy, and Yu. V. Paramonov, "Shlyakhi Realizatsii Skladnikh Biotekhnichnikh Sistem" [in Ukrainian], VISN. AN USSR, 1972, No 11, pp 33-40.

26. G. I. Sidorenko, "Kibernetika i Terapiya" [Cybernetics and Therapy], Moscow, "Nauka," 1970, 191 pages.

27. P. V. Bundzen, and A. S. Tsukerman, "Use of the Principle of Biocontrol in Neurophysiological Research," in "Metody Klinicheskoy Neyrofiziologii" [Methods of Clinical Neurophysiology], Leningrad, "Nauka," 1977, pp 317-340.

28. V. M. Akhutin, "The Principles of Construction of Complexes for Continuous Monitoring of the Human Organism and Automatic Normalization of Its States," in "Bioeletricheskoye Upravleniye. Chelovek i Avtomaticheskiye Sistemy: Tr. Mezhdunar. Simpoz. po Tekhn. i Biol. Probl. Upr. (Yerevan, 24-28 Sent. 1968)" [Bioelectric Control. Human Beings and Automatic Systems. Proceedings of the Symposium on Technical and Biological Control Problems (Yerevan, 24-28 September 1968)], Moscow, "Nauka," 1970, pp 519-533.

29. P. V. Bundzen, and A. V. Chubarov, "Theoretical Premises and Ways to Use Functional Modeling in Neurophysiology," in "Modelirovaniye v Biologii i Meditsine" [Modeling in Biology and Medicine], Leningrad, "Meditsina, 1969, pp 97-106.

30. A. M. Zingerman, D. M. Menitskiy, and L. S. Khachatur'yants, "Self-Organization of the Sensomotor Functional System under Conditions of Feedback Delay (Visual Afferentation from Results of Activity)," USPEKHI FIZIOL. NAUK, 1974, No 3, pp 59-81.

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